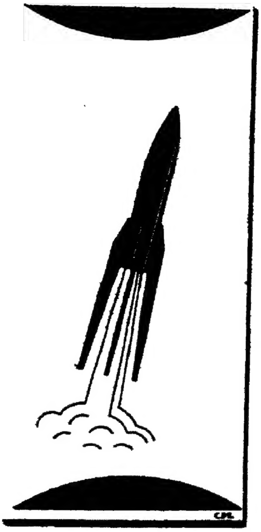
ROCKET RESEARCH

HISTORY AND HANDBOOK



Constantin Paul Lent

Diplomа Engineer - Industrial Designer

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DEDICATED TO THE PIONEERS IN ROCKETRY

ALL OVER THE WORLD

This is a wartime book produced in full compliance with government regulations for conservation of paper and other essential materials

CONTENTS

PREFACE **PAGE**

DEFINITION AND GENERAL HISTORY OF THE ROCKET 1

EARLY RESEARCH 27

RESUME OF EARLY EXPERIMENTS BY THE AMERICAN ROCKET SOCIETY........ 33

THE THEORY OF ROCKET OPERATION 41

PRACTICAL APPLICATION OF THE JET-PROPULSION MOTOR 71

PRACTICAL HINTS TO EXPERIMENTERS 85

POTENTIAL ADVANTAGES OF HOT AIR JET-PROPULSION 101

LIST OF ILLUSTRATIONS, PLATES AND TABLES

— ILLUSTRATIONS —

PICTURE OF THE AUTHOR C. P. LENT (Vice President A. R. S.)

PICTURE OF MR. CEDRIC GILES (President A.R.S.)

FIG. 1—Cross-Section of the Earth's Atmosphere 3
FIG. 2—An Imaginary Landscape of the Moon from the German Film "The Girl in the Moon", with a rocket in the background 4
FIG. 3—An early Rocket Launching Field 5
FIG. 4—Diagram of Rocket reaction principle 6
FIG. 5—An early experimental liquid propelled rocket 6
FIG. 6—An old French print of jet rotots from an aerial machine 6
FIG. 7—A copy of an old patent drawing showing a rocket plane 6
FIG. 8—Dr. Robert H. Goddard and one of his rockets 7
FIG. 9—Dr. Goddard and a view of one of his rockets 8
FIG. 10—The sixty-foot launching tower at Roswell, New Mexico employed by Dr. Goddard...... 8
FIG. 11—Dr. Goddard and his first liquid rocket 9
FIG. 12—Two early designs of Gun-Powder propelled craft 9
FIG. 13—The Valier and Heylandt rocket car 10
FIG. 14—The Valier Regenerative liquid fuel motor 10
FIG. 15—The Raymond Tilling Rocket 11
FIG. 16—The trajectory of a Tilling rocket 11
FIG. 17—The Valier multiple nozzle motor 12
FIG. 18—Three designs of liquid fuel rockets 12.13

FIG. 19—A photograph of the "Bazooka" rocket gun 13
FIG. 20—An A.R.S. rocket and test stand 12 13
FIG. 21—Two drawings of Rocket Guns 14
FIG. 21a—The famous Russian rocket gun "Katusha" 15
FIG. 22—An early rocket bomb design 15
FIG. 23—The latest instrument of destruction—the Robot Bomb 16
FIG. 24—The "Snare Rocket" used by the British 17
FIG. 25—The "Snare Rocket" ready for firing 17
FIG. 26—An early design of mobile anti-aircraft gun 18
FIG. 27—A Tilling rocket exploding 19
FIG. 28—One of the first Rocket Planes 20
FIG. 29—The Italian Caproni-Campini hot air jet plane 21
FIG. 30—A study of an early rocket gun 22
FIG. 31—The gun ready for firing 22
FIG. 32—A Russian Multi-Tube Rocket Gun 23
FIG. 33—A Gerhard Tucker Rocket 24
FIG. 34—A Rocket Torpedo 25
FIG. 35—The "Spear or Arrow Rocket" by the writer 25
FIG. 36—Can this be another secret weapon? 26
FIG. 37—A diagram of a rocket motor 27
FIG. 38—A Rocket Launching Field 28
FIG. 39—A Degenerative motor and curves of thrust 29
FIG. 40—Flight of an experimental rocket by the A.R.S. 31
FIG. 41—Stability tests by the A.R.S. 32
FIG. 42—View of a field for testing rockets 34
FIG. 43—Rockets used for the stability tests 35
FIG. 44—Rocket and parachute in the air 36
FIG. 45—Rocket and parachute on the ground 37
FIG. 46—A Test Stand by the A.R.S. 38
FIG. 47—An early and a degenerative motor 39
FIG. 48—A photograph of a field test by the A.R.S. 40
FIG. 49—An advance design of a portable test stand 44
FIG. 50—The head of the Spear Rocket developed by the writer. This rocket consists of two tandem cylinders and the nozzle is the portion under the hood and around the stem.......... 44
FIG. 51—A two-step Gun-Powder Rocket 46
FIG. 52—Two types of liquid fuel motors 47
FIG. 53—A design for a tandem liquid fuel rocket 51
FIG. 54—A diagram 52
FIG. 55—Piping Scheme of a proving stand 53
FIG. 56—A cross-section through the writer's Spear Rocket 56
FIG. 57—A diagram and curve 57
FIG. 58—A diagram and curve 58
FIG. 59—Design of a Launching Rack and Details 59
FIG. 60—Diagram 60
FIG. 61—Two Diagrams 63
FIG. 62—Diagram of a Flat Nozzle 63
FIG. 63—Diagram and Curve 64
FIG. 64—Steering mechanism diagram 65
FIG. 65—A pulsating liquid fuel motor 67
FIG. 66—Schematic Drawing 67
FIG. 67—A Curve 69
FIG. 68—A Curve 69
FIG. 69—A monel metal nozzle motor 69
FIG. 70—A semi-degenerative motor design 69
FIG. 70a—A cross-section through the Spear Rocket designed by the writer 70
FIG. 71—Another Secret Weapon 70
FIG. 72—The Russian Rocket Bomb 70
FIG. 73—The Jaumotte micro-meteorograph 72
FIG. 74—Sounding Balloon meteorograph 73
FIG. 75—Range Finder in action 74
FIG. 76—A Gun-powder rocket zooming skyward 75
FIG. 77—A diagramatic view of the Tilling rocket 76
FIG. 78—A Campini design for a jet-propelled boat 76
FIG. 79—Handley "Centrifuge" fireboat 76
FIG. 80—Tilling rocket with the wings open 77
FIG. 81—Dr. Fergusson's weather rocket instrument 79

FIG. 77—A diagramatic view of the Tilling rocket 76
FIG. 78—A Campini design for a jet-propelled boat 76
FIG. 79—Handley "Centrifuge" fireboat 76
FIG. 80—Tilling rocket with the wings open 77
FIG. 81—Dr. Fergusson's weather rocket instrument 79
FIG. 82—A Barometric parachute release 80
FIG. 83—Another type of parachute release 80
FIG. 84—Rocket radio control diagram 81
FIG. 85—The Spear Rocket and its application to aircraft 83
FIG. 86—The Rocket lighter than air craft 84
FIG. 87—The jet-propelled flying wing 84
FIG. 88—A simple way to attach covers to liquid containers 86
FIG. 89—Another simple way to attach covers to cylinders 87
FIG. 90—Thrust curves for powder rockets 88
FIG. 91—A cross-section through a "6 lb." gun-powder charge 88
FIG. 92—Two syphoning methods for liquid oxygen 90
FIG. 93—Showing guide rails for plane rockets 90
FIG. 94—Two types of liquid oxygen funnels 91
FIG. 95—A design for fuel and stabilization system 92
FIG. 96—A centrifugal fuel feed and gyroscope 92
FIG. 97—An instant trigger release for fuel valves 93
FIG. 98a—Template for plastic rocket shells 94
FIG. 98—Suggestion on pressure fuel feeds 95
FIG. 99—Various motor designs 97
FIG. 100—How public interest in rockets can be capitalized 98
FIG. 100a—A Tilling rocket on the ground 98
FIG. 100b—German Rockets zooming skyward 98
FIG. 101—More motor designs; some good, some bad 99
FIG. 102—The Campini design for a hot air jet aircraft 100
FIG. 103—Cross-section through a jet reaction plant 100
FIG. 104—Photograph of the Campini plane 100
FIG. 105—The Robot Bomb and how it works 102

PLATES

PLATE I—Test Stand of the American Rocket Society 36 37
Plate II—Early Rocket Vehicles 36-37
Plate III—Various Rocket Devices used for the War Effort 42-43
Plate IV—The Bazooka and the Radio Bomb 42-43

ALL Photos

Courtesy

THE AMERICAN ROCKET SOCIETY

TABLES

Nozzle in Inches Diameter — Combustion Chamber Pressure 27
Blast Chamber Metals (Table I) 45
Fuel Tank Metals (Table II) 49
Refractories (Table III) 49
Plastics (Table IV) 49
Heats of Combustion of Various Fuels by Weight 54
Heats of Combustion of Various Fuels by Volume ....
Form Factor for Spherical tanks 86
Composition of Black Powder for Rockets 89
Summarized Data on Small Rocket Charges 89
Congreve Rockets 89
Sq. ft. of silk per lb. of load and drop of ft. per sec. for parachutes. 90

NOTICE: For the Index and List of Patents on Rockets, see the other side of the Book.

It is kindly requested that readers report to the publishers any discrepancies or mistakes found in the text.

IN THE FUTURE, THAT NATION WHICH
WILL BE MOST ADVANCED IN ROCKET RESEARCH,
WILL CONQUER THE WORLD.

PREFACE TO THE SECOND EDITION

The first edition of "**ROCKET RESEARCH**" was literally taken off my hands. The present second edition has been put out under great difficulties due to labor and paper shortages. Were it not for the wide interest this book has aroused and the great number of orders already received for the second edition, I would never have attempted to print it again.

Rocketry is still in its infancy and like a child, it grows fast every day. In the period of a few months between the first and second edition, Rocketry went through many new developments, therefore, and I have added a great deal of new material to this book to bring it up to date. Note the new cuts of rockets and hot air jet designs.

I wish to thank the various publications which were kind enough to review the first edition of "**ROCKET RESEARCH**", and also the readers who made helpful suggestions in correcting a few mistakes that are unavoidable in the first edition of a book of this kind.

Here are a few excerpts from book reviews:

"Comprehensive in its scope, although much material is necessarily restricted for reasons, this book describes the basic principles of modern rocketry.

"Rocketry, as Mr. Lent points out, is still in its infancy and it is pardonable to inject into any serious discussion regarding its future....some advanced thoughts with a sparkle of guesswork here and there".

"SKYWAYS"

"Written by an industrial designer who believes that the nation 'most advanced in rocket research will conquer the world', this research and handbook is filled with illustrations, formulas and tables helpful in rocket design".

"FLYING"

"Lent's book is indeed a timely one. It is up to date....Consideration is given to the discussion of propellents, rocket designs, applications and tests. The volume is profusely illustrated with engineering and phantom drawings, in addition to including numerous tables and propellent formulas."

"WESTERN FLYING"

"ROCKET RESEARCH." "The author published it himself after commercial publishers to whom he submitted the manuscript (as he explains in the perface) thought it premature because so much war research cannot be told. Much of this interesting book is devoted to the author's own experience as a rocketeer".

HERALD-TRIBUNE
BOOK REVIEW SECTION

"A handbook and history of the many interesting experiments made by man in his field of flying, by a noted engineer and industrial designer. Mr. Lent describes early research, the first rockets, and those used today by allied and enemy armies. Illustrated, the book also contains many valuable hints for experiments in this field."

"WESTCHESTER FEATURES
SYNDICATE

"Thank you for the copy of ROCKET RESEARCH (which I received recently). The book shows extensive study of the field. Further, the illustrations are very extensive, but for that very reason they include much that is speculative and untried, perhaps this is unavoidable in so new a subject."

Dr. R. H. GODDARD

"A copy of your publication ROCKET RESEARCH HISTORY AND HANDBOOK came to my attention today at the War Department....As an author and writer on Rockets myself, I can well appreciate the splendid job you have done in your handbook."

ROBERT N. FARR
SCIENCE SERVICE

PREFACE

Knowing that many people are genuinely interested in the technical and commercial aspects that modern Rocketry can offer and that others are only on the lookout for the revolutionary and the spectacular, in writing this book, my intent was to appeal to both, but more particularly to the former. Now, without question there are many books on rockets in circulation, some recent ones and some old. Therefore it is sincerely hoped that this new addition might be interesting and informative enough as to not just fill another empty space upon somebody's bookshelf.

Rocketry, as it stands at present, is only in its infancy and it is pardonable to inject, into any serious discussion regarding its future possibilities, also some spectacular thought. With this in mind, I am pleased to present to the reader not only subjects of theoretical and practical knowledge but also data on rockets experiments and some advanced thoughts as to its future with a sparkle of guess work here and there.

The reader will discover this book to be full with illustrations, formulas and tables helpful in rocket calculation and design. In the photographs he will also find records of actual experiments of the past and present. But, I wish to pass a warning regarding said formulas and tables. The former are the findings of tests, theory and guess work, while the latter are only ninety per cent correct; still both are safe to use although the results might be slightly incorrect.

In compiling this book I have drawn extensively from experimental data and field tests of the American Rocket Society and I dedicate one complete chapter of this book to the work that has been done by its members in the past.

Furthermore, having future developments in mind and wishing to help those who are genuinely interested in doing some work of their own, I have included in this book many shop drawings in detail and dimensions for rockets motors, rockets, launching racks, etc. Those who would like to test their skill in this new field will find it helpful at first to build their rockets according to these drawings while improving as they go.

Here I must sound another warning. Do not trust rockets! Rockets have the tendency to misbehave when the least expected. Therefore, constant carefulness and watchfulness should be exercised. Never stand near motors at test periods and always check and recheck the fuel connections leading to and from the motors before firing. A deep ditch or trench should be provided for the spectators and the experimenters many yards away, when launching rockets, and all operations for launching the missile should be studied before hand. All such parts of the rocket as piping connections, fuel tanks, etc., must be light but sturdy, and watch for leaks. Disregard of these and other rules might bring regretful consequences.

The Author

CONSTANTIN PAUL LENT
Vice President of the
American Rocket Society

For the young experimenters I am also including a chapter with practical hints for rocket construction and operation. For the informative type, I have included a short but comprehensive history of Rocketry.

Note that the work that has been done in the military field has been also presented in outline, also such long shot guesses regarding the so called "Secret Weapons". In addition I took the liberty in injecting some work of my own, practical or otherwise.

I also find it appropriate, if not tactful, in making a few comments of my own as to the original object of rocketry, i.e., the subject of Interstellar Travel. I wish here to remind some "very practical souls" that Interstellar Travel is a thing of the near future and not just another idle dream. Although I do not wish to dwell in this book on this matter, I expect to make it my business in a new issue, if I ever undertake again to write on this fascinating subject.

Oh yes! Just a few words regarding the publishing of this manuscript. I had originally approached a number of publishers, but all have commented that a book of this kind is premature and that after the war there will be much more material and information available and that therefore I should wait. This might be true. But, I am not a prophet and I can not foretell the end of this war. In between, any knowledge on rockets is useful. With this spirit in mind, I have published this book privately and through my own concern the PEN-INK Publishing Company.

By the Author

Constantin P. Lent

CONSTANTIN PAUL LENT
July 11, 1944
New York.

MR. CEDRIC GILES

President of the American Rocket Society since 1943. Has been Secretary since 1940 and joined the A.R.S. in 1931.

DEFINITION AND GENERAL HISTORY OF THE ROCKET

The rocket, as we now know it, is essentially a tubular case, closed at one end, and fitted at the other with a constricted opening or nozzle, and containing a quantity of combustible fuel of such nature that when the combustion begins the gases and flame generated thereby rush through the nozzle. If unrestrained during this state of combustion, a rocket will tend to move with great rapidity in the direction away from the nozzle end—that is, in a direction opposite to that traveled by the expelled gases. This action is due to the working of the recoil principle, and upon it the value of the rocket depends. In essentials the rocket is an engine without moving parts; the simplest and under proper conditions the most efficient of the various devices for transforming energy into motion. Its discoverer, like the inventor of the wheel and the lever, will probably be forever unknown. We are certain that the principle of the rocket has been known for centuries, perhaps for thousands of years.

For its beginning we must perhaps go back to the ancient Chinese, from whom the rudiments of all pyrotechnic art are believed to have come. The Greeks were also adept at the use of flaming projectiles and other pyrotechnics. The first mention of what was unmistakably a rocket is to be found in a 13th Century collection of recipes known as the Liber Ignium of Marcus Graecus. The later introduction of gunpowder in Europe and the interest in gunnery stimulated the art of fireworks pyrotechny. By the beginning of the 15th Century rockets were used not alone for celebrations but also in warfare, supplementing the crude and unwieldy cannon of the period. From the 15th to the 18th centuries the principal advances in rocket design and fuel were made by the pyrotechnists. Early in the Eighteenth Century the brothers Ruggieri, Italian fireworks artists, were invited to Paris and later to London, where they startled Europe with the beauty, artistry and ingenuity of their displays, incidentally bringing with them their word, **rochetta,** which has been incorporated in a modified form in our language.

Thus the making of rockets was already a great art and something of a science at the beginning of the 19th Century when Sir William Congreve and his predecessor at the Woolwich Laboratory in England took up the work of adapting them to the needs of war. Congreve was the first scientist of note to take up rocketry. It was largely through his enthusiasm and effort that the rocket in the 19th Century became something more than a toy. In 1805, when Sir Sidney Smith's expedition set out against Boulogne it was accompanied by Congreve and a number of boats specially fitted for firing salvos of rockets. Bad weather balked the first attempt, but finally in 1806 Boulogne was bombarded by rocket projectiles. Great numbers of them, discharged in volleys from the special boats, were hurled into the town, where they did great damage, setting fire to houses and spreading terror among the soldiers of the garrison. The Congreve rockets, which were used again in 1807 by the British against Copenhagen, weighed 32 pounds each, of which seven consisted of carcass composition and the remainder fuel. They were three feet, six inches in length and four inches in diameter, and had metal cases and an improved nozzle. The only stabilizing device, however, was the stick fastened to the side like those of ordinary skyrockets. It was 15 feet long and 1½ inches in diameter. Upon landing, the rockets quickly burst, exposing a great mass of flaming surface in the case of incendiary projectiles, or hurling iron and lead pellets like shrapnel.

In 1812 the Field Rocket Brigade was formed and a year later it was sent to join the Allies before Leipsic. So marked were the results that the Rocket Brigade took part in virtually every important subsequent battle against Napoleon, distinguishing itself particularly in the final contest at Waterloo. By the end of the 19th Century military rockets had become obsolete. They were cranky, undependable, inaccurate and more often dangerous to friends than enemies; whereas the rifled bore, breech-loading, independent recoil and smokeless powder gave an increasing advantage over them.

The modern high-altitude rocket owes at least two of its features to Congreve and his successors; the metallic, streamlined case and the stabilizing fin or vans, introduced by Hale. To the peaceful rockets of the 19th Century it owes another — the idea of multiple or step construction that may some day be a vital part of interplanetary rocket design. The first application of the rocket as a line carrier in life saving was made by the Cornishman Trengouse, in 1807. The chief problem from the first was the achievement of distance without too great an expenditure of fuel. In 1855 Colonel Boxer, of the Royal Laboratory, produced a rocket of great range by joining two ordinary rockets end to end in such a manner that when the first had burnt out the second came into action. This scheme had been suggested earlier by a man named Frazier, who apparently failed to make any practical test of it.

The period of **modern** rocket research begins with the work of Dr. Robert H. Goddard, of Clark University. Rocketry in the 20th century also received great impetus due to the demand for a better and simpler device to reach higher altitudes facilitating the collection of weather data and to replace the cumbersome and slow weather balloon. Only a small portion of the stratosphere had been sounded by weather balloons because of the limitations in height that they can rise and from Fig. 1 it can be seen that a lot remains to be learned of higher strata in the atmosphere by the use of rockets which incidentally are the only medium known to fly in vacuum.

The idea of using rockets to reach great altitudes and even interplanetary spaces, goes back as far as 1660, but it remained for Dr. Goddard to make the first experiments and to write the first scientific work on the subject. His report, apparently prepared two or three years earlier, was published by the Smithsonian Institute in 1919, to be followed in 1923 by the book of Professor Hermann Oberth of Mediasch, in Transylvania; in 1924 by that of Max Valier, of Munich; and in 1925 by the study of Dr. Walter Hohmann, of Essen, and the monumental work of Robert Esnault-Pelterie, of France, who gave the new science of Astronautics its name.

Dr. Goddard, in his first laboratory experiments, backed by a small grant from the Smithsonian Institution, definitely proved the fact — then much doubted — that the rocket would work efficiently in a vacuum. Of equal or greater importance, he worked out in detail the mathematical theory of the multiple or step rocket, and stated that it was without doubt theoretically possible to build a rocket by this method that would reach the moon. Publication of his report caused a great sensation among scientists and the newspaper-reading public. Dr. Goddard turned back to his work with intense competition on the part of the Germans, Austrians and French to spur him on, in addition to his own zeal for discovery. Furthermore, Dr. Goddard was the first scientist to conduct extensive experiments on large liquid fuel rockets which had been launched from specially designed launching racks in Roswell, New Mexico. Figures 8, 9, 10 and 11 are showing some of the work done by this famous scientist.

But the most dashing if not the most popular of early rocket scientists was Max Valier. His offering to the development of rockets consisted first of experiments, in partnership with Fritz von Opel, tending to adapt the recoil principle to automobiles, sleds and aircraft. His most important work, however, was done with Dr. Paul Heylandt, in experiments with liquid fuels. Their first recoil motor, announced in 1929, weighed seven pounds and could develop 40 horsepower on a fuel of liquid oxygen, alcohol and benzine. By April of this year they had improved it so that, with the addition of only four pounds of weight they had been able to generate maximum output of 220 horsepower. On May 17, 1930 the motor exploded and Valier was killed—the first martyr to the growing science of astronautics. Figures 12, 13 and 14 show some of the work done by Von Opel and Vallier. Opel's work mostly has been with dry fuel rockets while Vallier also experimented with liquid fuels. An interesting design is the regenerative rocket motor shown in Fig. 14, by Vallier.

Only one European has made achievements of sufficient importance to rank him with Dr. Goddard. He is Professor Hermann Oberth. In 1928 or early 1929 Oberth joined forces with the UFA Film Company under an agreement by which the Company guaranteed to finance the building of a rocket in return for technical aid in filming a drama called "The Girl in the Moon" Oberth selected a small island in the Baltic and plans were drawn up for building the rocket there.

It was six feet high and ten inches in diameter, constructed of steel with an outer covering of magnesium to protect it against changes in diameter. Oberth had told reporters that the fuel, consisting of hydrogen and oxygen, would burn for 80 seconds and that he hoped it would accelerate sufficiently to give the rocket a speed of 4,000 yards a second. It is not known if this rocket had been ever shut, but the results of this work was the filming by UFA of the film, "The Girl in the Moon" a photo in Fig. 2 showing an imaginative landscape in the Moon with the rocket in the background submerged in the dusty soil of this romantic satellite.

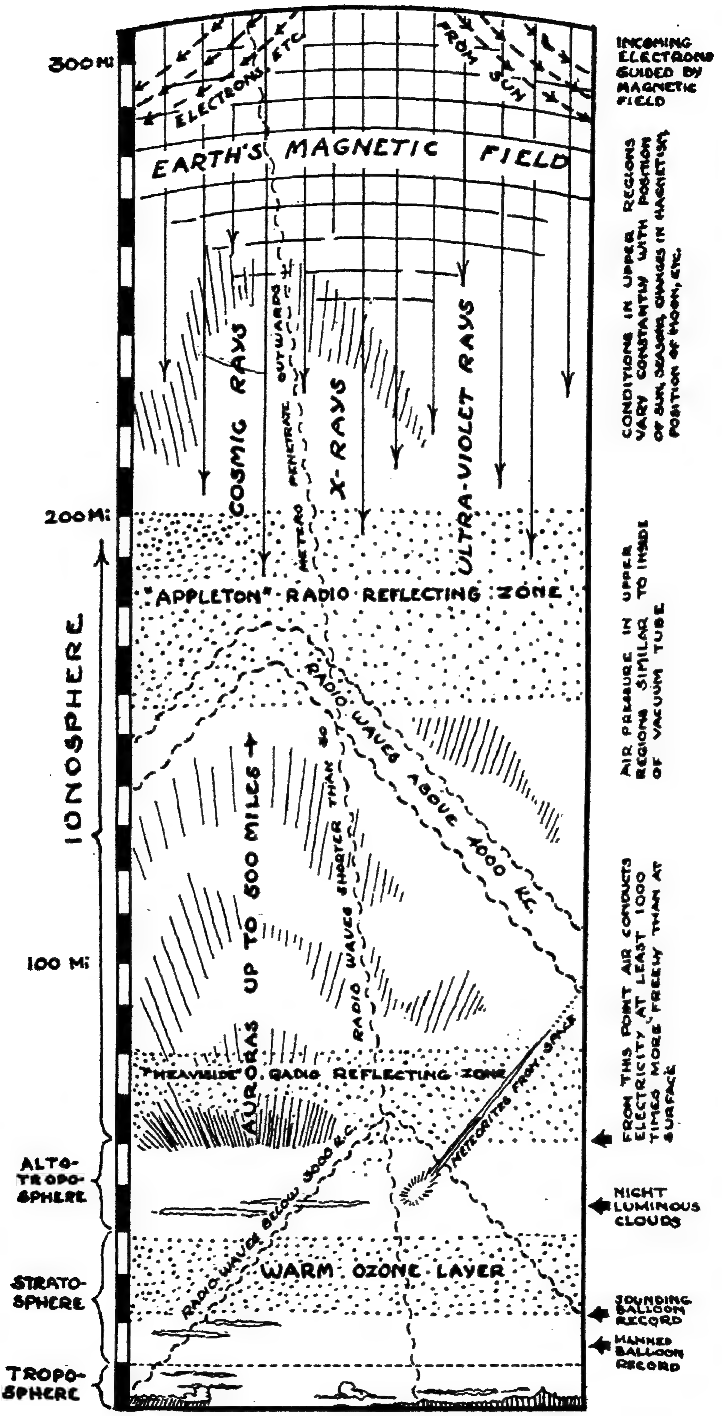
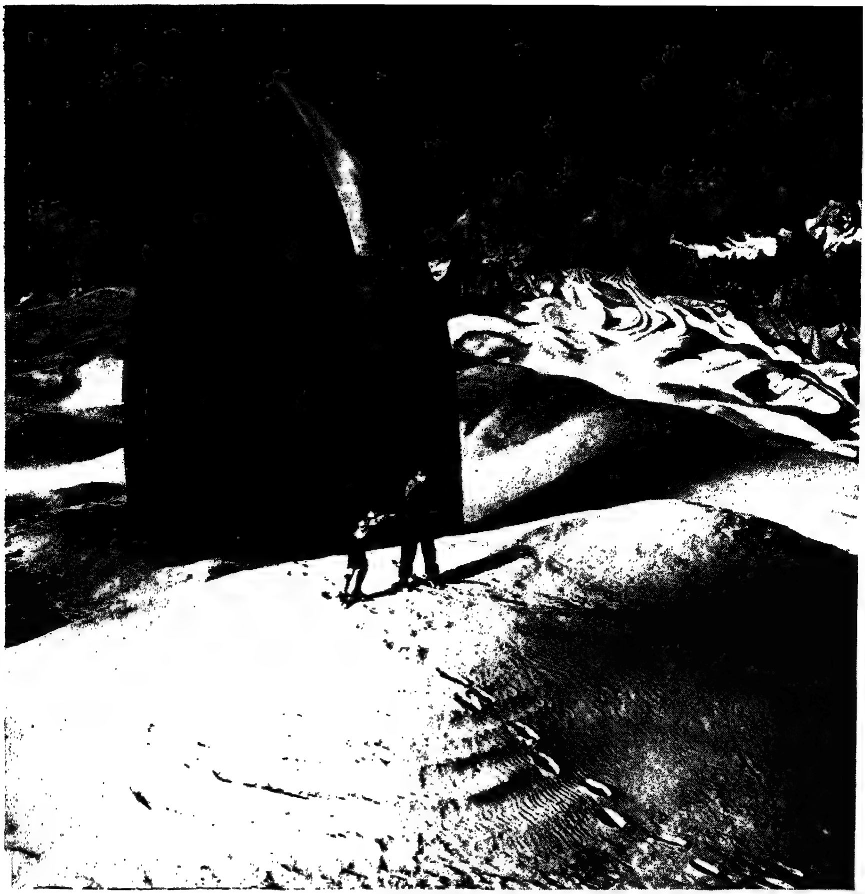

300 Mi
200 Mi
100 Mi
IONOSPHERE
ALTO-TROPO-SPHERE
STRATO-SPHERE
TROPO-SPHERE
ELECTRONS, ETC
FROM SUN
EARTH'S MAGNETIC FIELD
COSMIC RAYS
METEROS PENETRATE OUTWARDS
X-RAYS
ULTRA-VIOLET RAYS
"APPLETON" RADIO REFLECTING ZONE
RADIO WAVES ABOVE 4000 KC
RADIO WAVES SHORTER THAN 80
AURORAS UP TO 500 MILES
"HEAVISIDE" RADIO REFLECTING ZONE
METEORITES FROM SPACE
RADIO WAVES BELOW 3000 KC
WARM OZONE LAYER
INCOMING ELECTRONS GUIDED BY MAGNETIC FIELD
CONDITIONS IN UPPER REGIONS VARY CONSTANTLY WITH POSITION OF SUN, SEASONS, CHANGES IN MAGNETISM, POSITION OF MOON, ETC.
AIR PRESSURE IN UPPER REGIONS SIMILAR TO INSIDE OF VACUUM TUBE
FROM THIS POINT AIR CONDUCTS ELECTRICITY AT LEAST 1000 TIMES MORE FREELY THAN AT SURFACE
NIGHT LUMINOUS CLOUDS
SOUNDING BALLOON RECORD
MANNED BALLOON RECORD

FIG. 1

Cross-section of the earth's atmosphere. Note that sounding balloons can reach the stratosphere but cannot go any higher. Only rockets can reach higher altitudes. Rockets are the only medium known that can fly in vacuum.



Courtesy of UFA

FIG. 2

An imaginary landscape from the UFA film "THE GIRL IN THE MOON". The men in the picture do not wear any protective suits which should imply that there is atmosphere in the moon, which of course, is a fallacy.

In 1920 Dr. Goddard began experimenting with liquid fuels for rockets—probably the first scientist anywhere to do so. By 1928 he had perfected a nozzle suitable for handling it, and had experimentally determined upon a mixture of hydrogen and oxygen as the best fuel. Several small shots prior to the summer of 1929 were made at Auburn, Mass., with these inventions and when they proved satisfactory he set to work at Worcester to make a final test of the fuel and method in a rocket which he hoped would reach an impressive altitude carrying a camera and a delicate barometer and landing by means of a parachute. It was this test which startled Worcester in the famous "shot of July 17.".

Dr. Goddard had erected a steel tower forty feet high in his accustomed proving ground, providing it with small rails to guide the rocket from its base to its apex. The rocket was nine feet long and 28 inches in diameter. Despite the confusing reports it was apparently not a step-rocket but was so constructed that the liquid fuel was exploded in a rapid series of blasts instead of continuously. When the rocket was touched off the roar of the explosions was heard for two miles. The newspapers in their first reports declared that the rocket had exploded and that the experiment had been a failure. It was only after some days that Goddard succeeded in making it clear that the attempt had instead been a brilliant success. Liquid fuel had been used successfully for the first time in an actual rocket flight. Though the altitude

FIG. 3

A rocket launching field with early experimenters ready to launch a tandem liquid propelled rocket. Note that the experimenters are protected by a deep ditch. The launching rack is tilted towards the ocean that can be seen in the background.

reached had not been as great as expected, the apparatus had worked perfectly and the parachute had brought the shell and its delicate instruments, which included a camera and a barometer, back to earth undamaged. Not without reason was the first shot of July 17 compared by Dr. Abbot of the Smithsonian Institution with the first flight made by Dr. Langley's heavier-than-air machine over the Potomac in 1896. It might better be compared with the completion of the first working steam engine, or with some other fundamental invention that caused a subsequent social revolution. No one can say what the effect will be when the penetration of interplanetary space, which by this exploit now had come within our grasp, becomes a possibility.

Thus the practical work of getting a liquid-fuel rocket actually into the air was a contribution of America, as were the three most fundamental achievements of modern rocketry. These, as listed by Dr. Abbot a year ago, were: (1) The discovery of the correct-angle gas orifice. (2) The successful introduction of continuously-burning liquid propellants, and, (3) The mathematical theory of the multiple rocket, together with the first practical measurements and tests in the fundamentals of rocket propulsion.

Now there is in space no matter against which to push. Ordinary means of psysical propulsion are therefore useless. The only physical law which can at present be utilized to obtain powered navigation in space is that of the recoil. In its simplest terms this is familiar to everyone who has fired a sho gun but I will here attempt to give a more detailed analogy, however, since up to the time of Goddard's experiments in 1919 there was doubt even in scientific circles as to whether power could be obtained in a vacuum.

Let us suppose four cubes of equal weight stuck together with a glue of dynamite to form a long narrow apparatus, four times as long as wide, see Fig. 4. In cube No. 1 we place our pay-load. The whole is set out in space and the problem is to move cube No. 1 to the left.

An explosion of the dynamite between cubes 2 and 3 divides the vehicle in half. Obviously both halves will fly apart at an equal rate of speed. But we are only interested in cube No. 1, which has moved to the left as desired. Now another explosion is caused between cubes 1 and 2 and these two quarters fly apart—cube 2 is jettisoned and cube 1, in which is our payload, is forced at still greater speed toward the left. Though inefficient in the extreme this is true rocket propulsion and it is obvious that it would operate in airless space. A more scientific expression of the law upon which it is based would be that the center of gravity of the whole

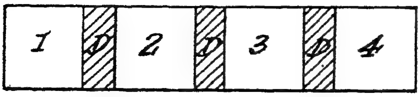
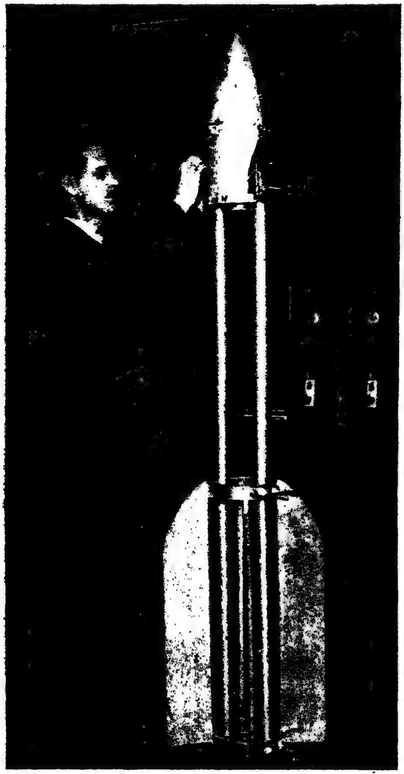


FIG. 4

vehicle (in this case the dynamite between cubes 2 and 3) remains unchanged in position by the explosion, due to the inertia of mass.

As elementary as it seems the above explanation of the reaction principle many problems had to be solved by scientists through the centuries to advance rocketry where it is now.

Having first solved the problems pertaining to fuel and the proper handling of same, the early experimenters turned their attention to design of proper motors. The design of the motor depended, of course, upon to fuel to be used and it was first necessary to build a container for the fuel. This assumed different shapes and had different requirements for various fuels. Properly speaking, it was found that it was not a part of the motor. The motor itself consisted of a fuel feed, an explosion chamber and an exhaust tube. The type of explosion chamber was dictating the form of the whole motor, and there were two possible types:



An early experimental liquid propelled rocket. The oxygen and gasoline cylinders are placed facing each other, the motor is located at the head of the missile, while a number of fins are secured to its lower end. Note its comparative size with its designer Mr. Pearce, a former president of the A.R.S.

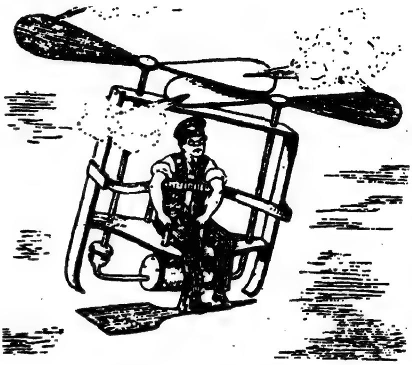


FIG. 6
An interesting old French print showing jet rotors on an aerial machine.

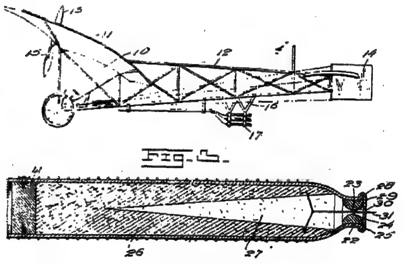
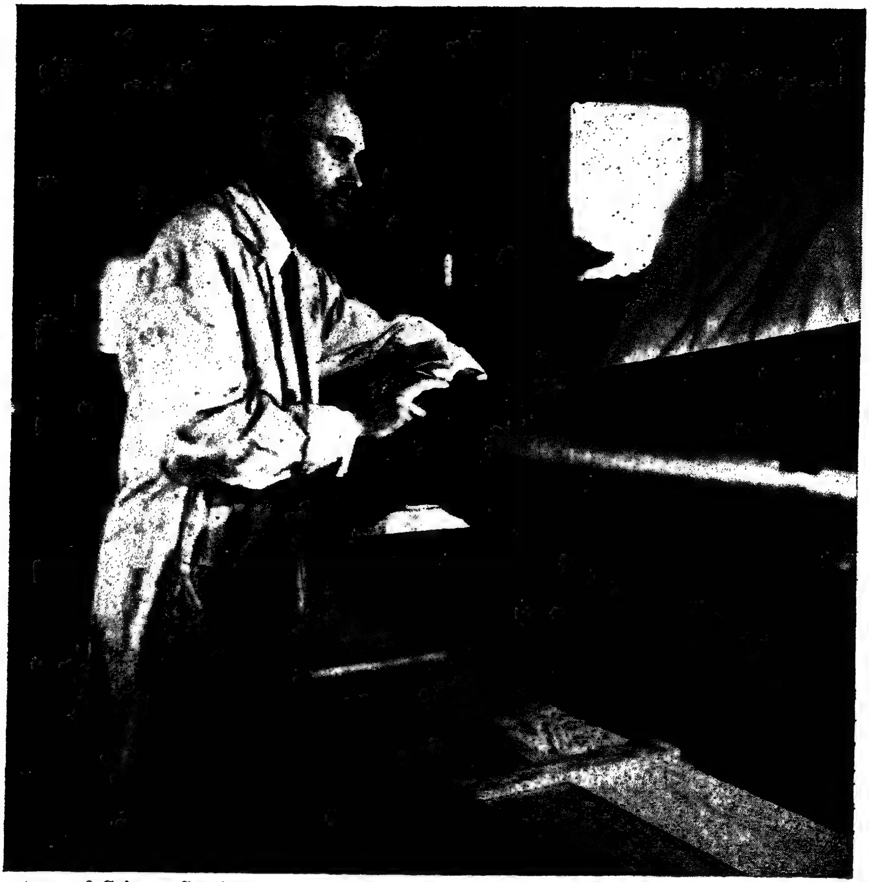


FIG. 7
A copy of a drawing of an old patent showing a rocket propelled plane and a cross-section through a powder rocket used in connection with this project.

(a) An equal pressure motor. In this there was a constant pressure in the explosion chamber. There was a constant explosion and a constant rush of gas or vapor through the exhaust. It was necessary to keep the explosion chamber supplied with fuel and to do this in spite of the enormous pressure requires a forced feed. Two methods were apparent: 1. the fuel chambers were under sufficient pressure all the time, in which case they had to be strong enough to stand it, or 2. some form of pump was used to inject regularly the necessary fuel.

(b) An explosion rocket was also pos-



Courtesy of Science Service

FIG. 8

Dr. Robert H. Goddard was one of the first experimenters to use a mixture of petroleum and liquid oxygen to propel rockets. He was extensively financed by the Smithsonian Institution, and he was responsible for many important developments in rocketry.

sible. In this the fuel was exploded in the chamber and the gas rushed out of the exhaust. There was little or no pressure in the chamber and a new charge was brought in to be exploded in its turn. Here also two methods of feed were possible. The fuel may have been under constant pressure, controlled by a valve which was to shut off the supply during the actual explosion, or there was a method of mechanically feeding the fuel as cartridges are fed into a machine gun. A brief reflection upon the problem indicated that the more even and steady the motive force were, the less was the strain put on the rocket structure and the occupants, if any, as well as the greater the motive efficiency. For this reason if the second or explosive rocket type were to be successful the explosions have to be extremely frequent—several each second. With these premise granted thare was no difference in practical efficiency, at least so far.

The next problem confronting them was that of safety. Fuels must be so handled that there is no danger of the whole fuel cargo being set into combustion at once. For this reason a detonating gas or fuel could hardly be used in an equal pressure rocket with the fuel in continuous forced feed into the combustion chamber. No screen could prevent back-firing into the mass of the fuel. One of Professor Oberth's designs used two gases—hydrogen and oxygen. The oxygen was heated by passing it through coils surrounding the explosion chamber. When it reached 700 degrees Centigrade it was sprayed into the explosion chamber under pressure. The hydrogen was vaporized and sprayed upon the heated stream of oxygen in the chamber. Immediate and continuous combustion occurred and with safety, for

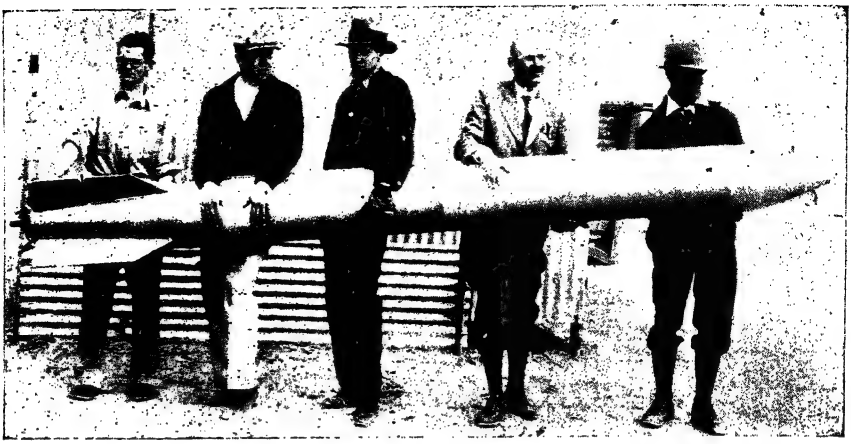


FIG. 9

Dr. Goddard, second from the right in the picture, is shown with one of his early rocket projectors. For many years he had been conducting test flights in New Mexico for the purpose of perfecting rocket stabilizing apparatus.

hydrogen and oxygen are neither explos- separately. So no detonating gas existed except that in the explosion chamber itself.

The weight of the fuel container, particularly if it proved necessary to install a cooling plant to maintain liquid oxygen at the necessary low temperature, become of great importance. If built as a single unit, it would have been exceedingly inefficient when the fuel was partially exhausted. The ideal was a container that shrank as the fuel was exhausted. The nearest to come to this ideal might have been a series of comparatively small fuel containers each of which was detached and discarded when its contents become exhausted. For solid fuels the problem was much simpler. Goddard suggested in 1919 a smokeless powder loaded in cartridges and fed machine-gun fashion into the explosion chamber. This was extremely safe and efficient, except that the weight of the cartridges was clearly waste. This waste might have been overcome by having the cartridges on an endless belt pass back into the fuel chamber after firing and being there automatically reloaded. It was thought that this same principle could have been adapted to liquid fuels, and would have even rendered possible a detonating gas fuel providing the empty cartridges were cooled before passing back into the fuel container for reloading. There was a distinct

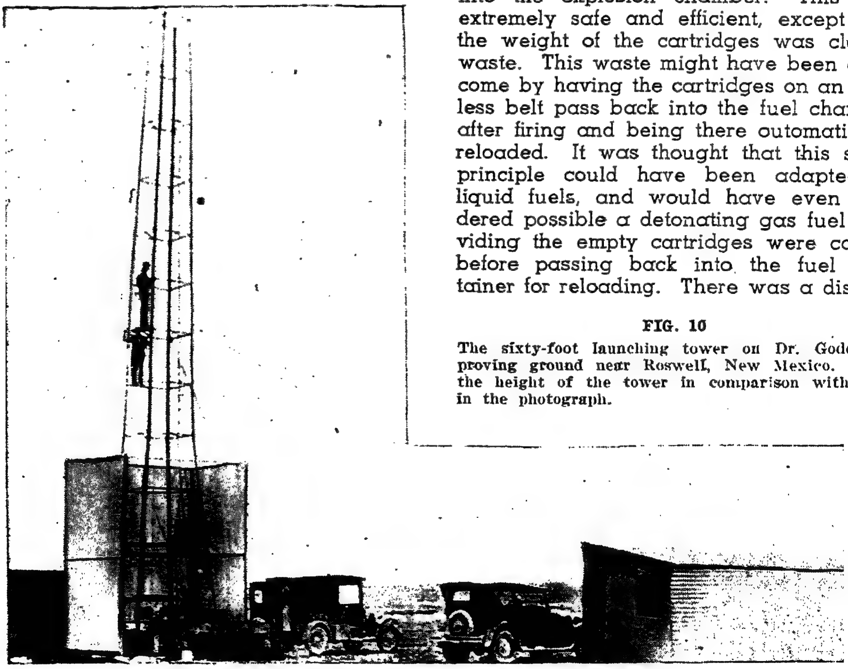


FIG. 10

The sixty-foot launching tower on Dr. Goddard's proving ground near Roswell, New Mexico. Note the height of the tower in comparison with men in the photograph.

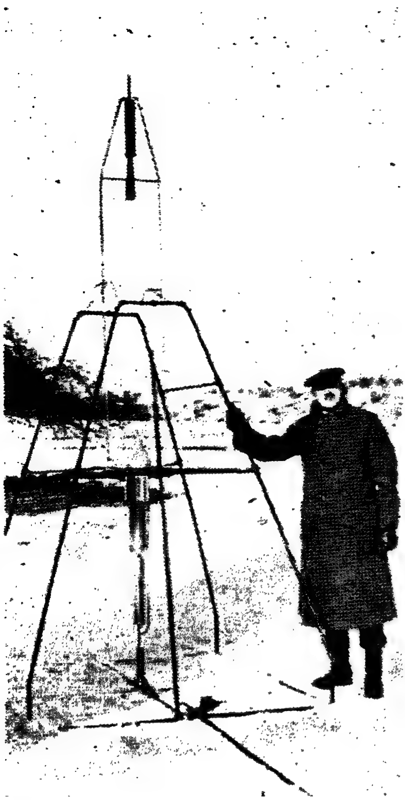


FIG. 11
Dr. Goddard and his first liquid-propelled rocket. The motor of the rocket is located at the upper portion while the tanks retaining the fuels are on the lower extreme end.

advantage in such a motor, since it was not necessary to force fuel into the explosion chamber against the enormous pressure existing there. This would have rendered possible an explosion type motor with extremely frequent explosions.

The ideal shape of exhaust was then computed, but as it is a purely mathematical calculation, it cannot be considered here and will be stated later on. It will be sufficient to say here that it was to be smaller at the start of the tube than the explosion chamber above it, and gradually to be widened to permit as free an expansion of the gases as possible, as well as take advantage of the work involved in that expansion. As the exhaust gases expand with extreme rapidity, and the exhaust walls widen; providing inclined planes against which the expansion pushes. This push was translated into a forward motion of the rocket itself.

Oberth had stated at that time that in a rocket of considerable size, the ideal form of exhaust is manifold. As one large exhaust subject to terrific pressure would be difficult and weighty in construction, many smaller exhausts should be used so that it becomes much simpler to provide the necessary structural strength without undue weight. And second, the pressure must be as great as possible in proportion to the pressure in the explosion chamber for the sake of efficiency. (See Fig. 17).

Some of the early designs of liquid fuel rockets are shown in Figs. 18 and 20 Note that all have separate tanks for each fuel which is in this case gasoline and liquid oxygen. The three rockets shown in Fig. 18 are of German design while the rocket shown in Figure 20 is a design by the American Rocket Society. This rocket had been successively flown to high altitudes. On the right of Fig. 20 is a simple test stand used by the Society to test the behavior of rocket motors on the ground.

The problems that confront the small group of scientists actively engaged in research on the subject of the rocket as a possible means of interplanetary travel, are numerous and admittedly difficult. It is generally conceded that, among the multitude of questions that await solution, not one is as critical as that of a suitable fuel or propellant for the rocket. It might be well, by way of introduction,

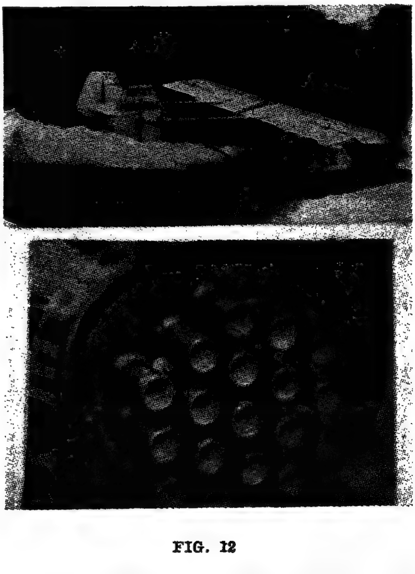


FIG. 12

Two early designs of gun-powder propelled rocket motors. The one at the top showing Van Opel Plane at take-off, and the one at the bottom a typical rocket battery arrangement for automobiles. Both of these designs have never passed over the experimental stage but they have been the forerunners of the present jet-propelled planes.

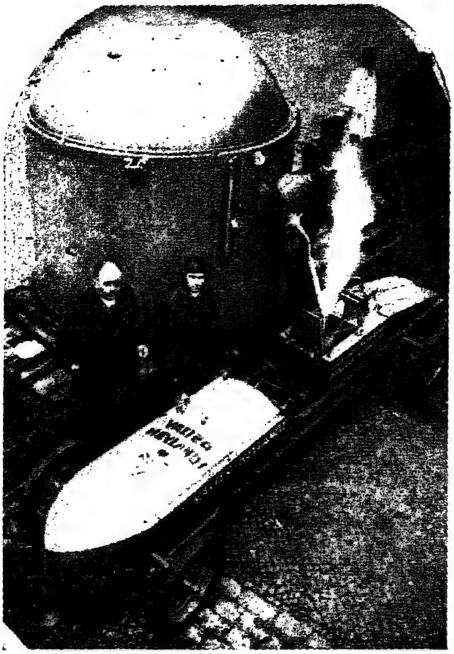


FIG. 13

An interesting design of Valier and Heylandt liquid rocket propelled car. The photograph shows both experimenters preparing for a test run.

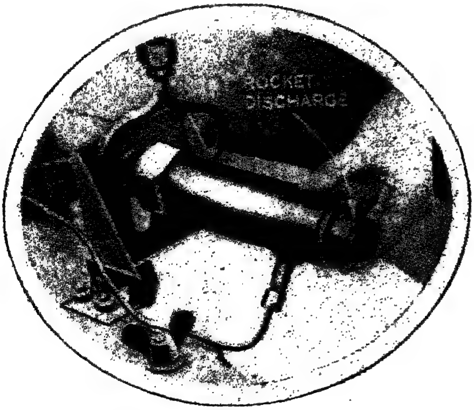


FIG. 14

A motor of regenerative design used by Valier in his experiments. Note the connection at the lower right, near the nozzle of the motor, for the injection of gasoline and the connections at the upper end of the motor for the injection of liquid oxygen.

to take up very briefly the elementary chemical principles involved in the development and use of a rocket fuel. Until we discovered the secret of atomic energy or radio-activity, we must content ourselves with those standard substances known as combustibles or fuels, which enter into a chemical union with oxygen, resulting in the evolution of heat and other forms of energy. In a rocket fuel it is essential that this chemical reaction known as combustion should result in the production of huge volumes of hot expanding gases, for it is these gases, operating on the recoil principle, that propel the rocket in space. In the burning of ordinary fuels the oxygen is derived from the surrounding air. In an explosive the chemical action is made independent of the atmosphere by including in the mixture one ingredient that supplies the oxygen. In addition the combustion takes place with such extreme rapidity that it appears almost instantaneous. Both the heat and the pressure derived from any given explosive are measures of the power to be obtained from the substance. The temperature of the reaction may run up to several thousand degrees, and the amount of heat per unit weight of explosive (measured by a bomb calorimeter) is one of the most important factors governing the power of an explosive. As for the pressures developed in a closed space by the detonation of an explosive, they are enormous. Actual tests show that in rifled fire-arms, the chamber pressures range from ten to twenty tons per square inch.

In the common type of pyrotechnic rocket, both early and modern, and even in the life-saving rocket of today, the propellant used is gunpowder. This explosive consists, as we know, of carbon, sulphur and potassium nitrate. The latter, being a strong oxidizing agent, will effect the rapid combustion of the two other ingredients, resulting in the evolution of large quantities of carbon dioxide and sulphur dioxide, as well as various solid products. Of considerably more power and adaptability than gunpowder are the various synthetic organic compounds that go under the name of high explosives. Such are nitrocellulose or guncotton, nitroglycerine, nitrostarch, various smokeless and blasting powders, dynamite, T.N.T. and a host of others. In all cases the oxygen for the combustion instead of being mechanically mixed with the other ingredients in the form of a nitrate salt or other oxidizing agent, as in gunpowder, is chemically united with the fuel molecule into a complex organic structure. The chemical configuration of the explosive molecule is more or less unstable and under the proper stimulus it undergoes a complete disintegration, resulting in the evolution of enormous volumes of gases. A cross section of a standard "6 lb" rocket charge of gunpowder is shown in Fig. 91. Note the long cone-shaped

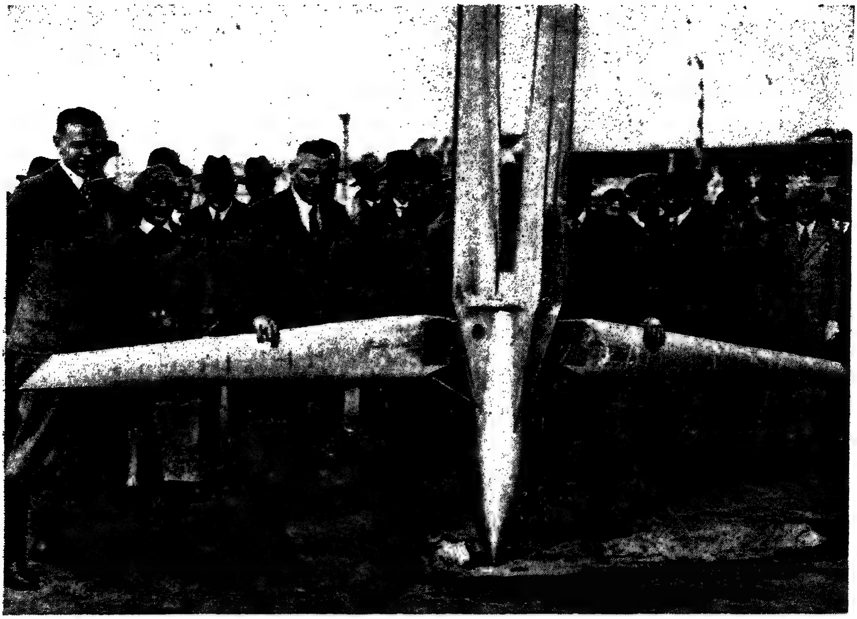


FIG. 15

A Raymond Tilling rocket developed in pre-war Germany. It was equipped with retractable wings and propelled with dry fuels. Tilling was eventually killed during one of his experiments in 1933.

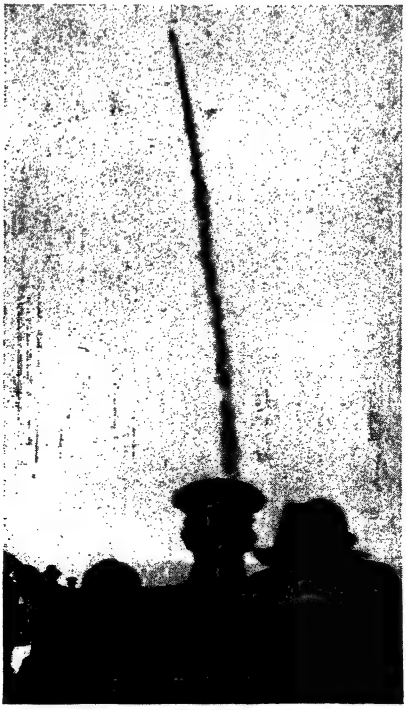


FIG. 16

Note the trajectory of one of the Tilling rockets. It has been reported that it flew over 6,000 feet.

hollow space within the black powder core in the back of the clay nozzle.

A vital factor in the operation of the rocket is the expulsion speed of the fuel, or more correctly, of the gases resulting from the combustion of the fuel. In the combustion chamber of the rocket, the fuel is made to combine with oxygen with explosive violence. The chemical energy stored up in the fuel is converted into heat and, in accordance with the rise in temperature involved, into pressure of the combustion gases enclosed in the chamber. Under this pressure the gases leave through the exhaust nozzle and attain a velocity that is known as the "expulsion speed". Being forced out at such high velocity, they exercise a back-pressure on the rocket and urge it forward. The work of propulsion is therefore obtained from the energy that is chemically contained in the fuel by way of heat, pressure and recoil. It is evident that, other things being equal, the greater the expulsion speed of the ejected gases, the greater the velocity of the rocket. The search for a suitable rocket fuel therefore concerns itself largely with the discovery of a substance which will give the highest possible expulsion speed.

From purely theoretical considerations it had been determined that a rocket in flight was most efficient when it was traveling at or near the expulsion speed of the ejected gases. Based on an ideal point of view all gaseous masses once expelled from the rocket should have no energy of their own—that is, they should have given up their entire quota of energy to the vehicle. It thus became manifest that, for the highest efficiency a rocket fuel was to give the greatest possible expulsion speed, and that the velocity of the vehicle must, perforce, to be enormous. But such velocities of both expelling gases and rocket, running into miles per second, were fundamentally essential for space travel.

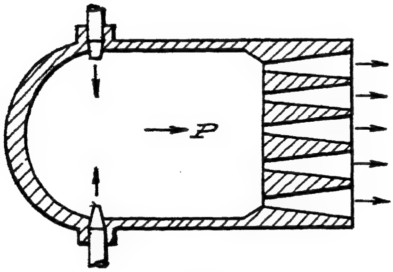


FIG. 17

The specifications for an ideal rocket are therefore:

1. It had to have the highest possible expulsion speed;

2. It had to have the highest possible specific gravity, so that the smallest containers were necessary;

3. The combustion had to be carried out safely, with the production of a steady motive power;

4. It was to operate in such a manner as to allow the smallest possible masses to be discharged in uninterrupted succession, and, 5. It had to be capable of efficient handling, involving the least possible trouble.

Goddard's first experiments, using ordinary black powder, such as is employed in the life-saving rocket, gave an expulsion speed of 1000 feet per second, and an efficiency of two percent. (Goddard defines "efficiency" in connection with a rocket fuel, as the ration of the kinetic energy of the expelled gases, calculated from their expulsion speed, to the heat energy of the fuel, derived from calorimeter measurements.) He next turned to smokeless powder and with this more powerful explosive Goddard obtained an efficiency of 64 percent and an expulsion of 8000 feet per second. All powdered fuel experiments, however, soon led to the same conclusion. They were difficult to control. Moreover, the energies contained in them, although great, was insufficient to propel vehicle into space. Goddard's calculations showed that to lift one pound of pay load beyond the Earth's gravitational influence would require 1000 pounds of black powder or 438 pounds of the best smokeless powder. The problem was therefore beyond all reason because it was obvious that it was impossible to find even a light enough container for the 438 pounds of fuel, not to mention the ship, equipment and passengers.

Goddard was then the first to turn to liquid fuels as the only practicable source of rocket power. Investigators abroad have followed suit, and for the next decade research was going on apace along the lines of liquid fuels and their utilization to propel a rocket vehicle. The best known of the rocket fuels and the one most likely to solve the problem of interplanetary travel was a mixture of liquid hydrogen and liquid oxygen. Goddard's calculations show that only 43.5 pounds of this mixture would be necessary to raise one pound of pay load beyond the earth's gravitational influence. Goddard's

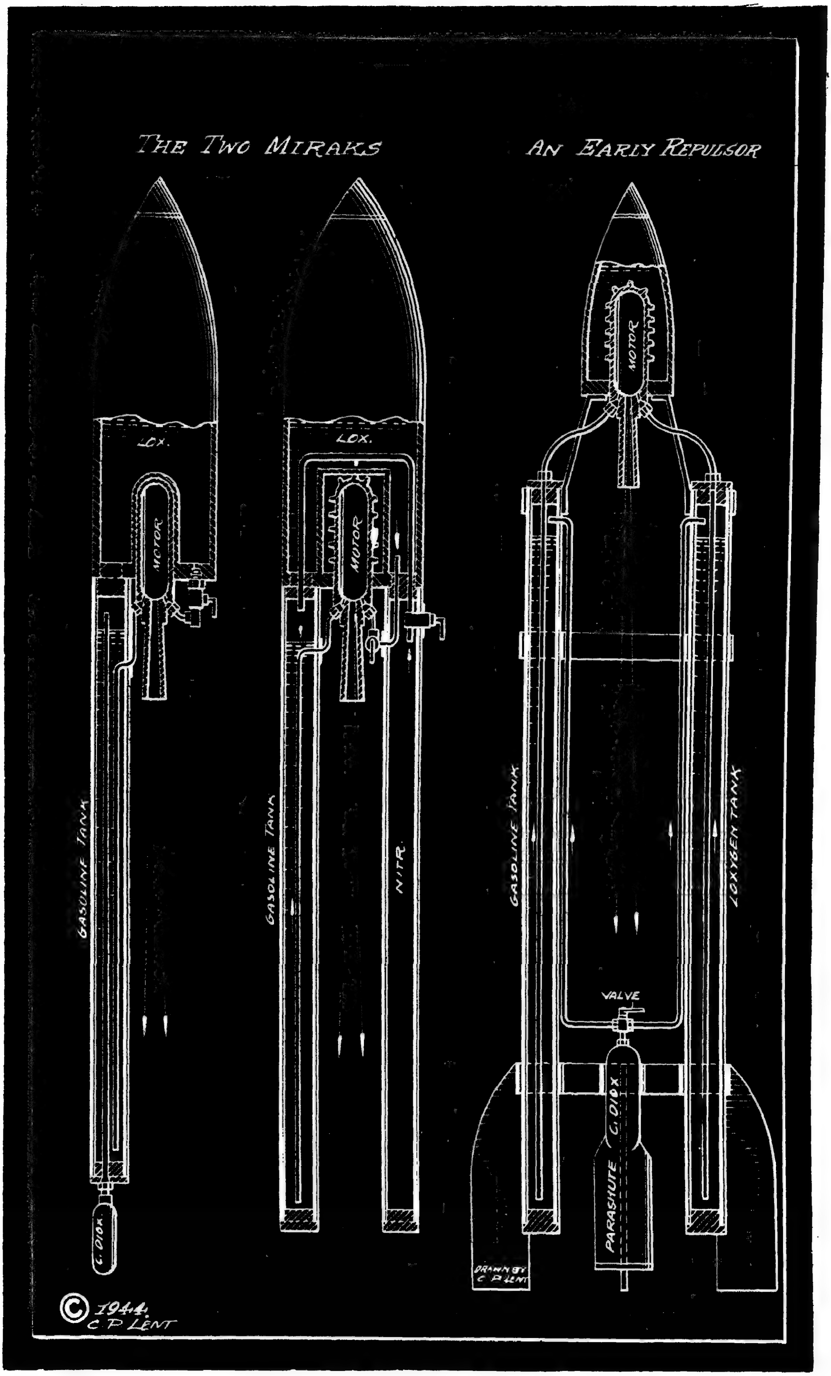
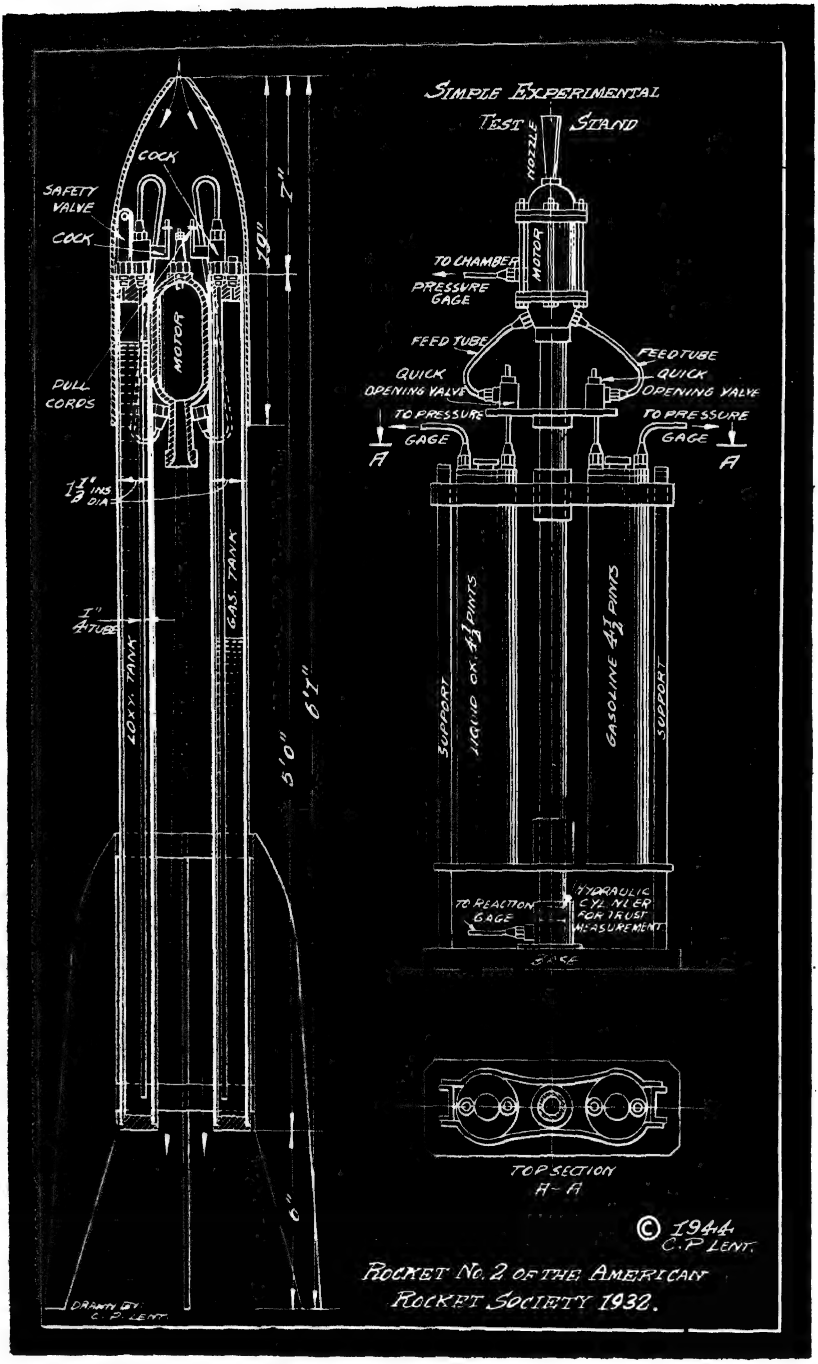

THE TWO MIRAKS
AN EARLY REPULSOR
LOX.
MOTOR
GASOLINE TANK
C. DIOX.
LOX.
MOTOR
GASOLINE TANK
NITR.
MOTOR
GASOLINE TANK
LOXYGEN TANK
VALVE
C. DIOX
PARASHUTE
DRAWN BY C P LENT
© 1944 C P LENT

FIG. 18

Three designs of liquid fuel rockets. The "Two Miraks" on the left have been built by the German Rocket Society. The one on the right is an early repulsor of the American Rocket Society. All three have distinctive fuel equalizing features. The first on the left has a carbon dioxide nipple; the second one has a separate nitrogen tank; and the third has a carbon dioxide cylinder,



SIMPLE EXPERIMENTAL TEST STAND
NOZZLE
COCK
SAFETY VALVE
COCK
MOTOR
PULL CORDS
1½" INS Ø DIA
1" Ø TUBE
LOXY. TANK
GAS. TANK
19"
7"
5'0"
6'7"
6"
TO CHAMBER PRESSURE GAGE
MOTOR
FEED TUBE
FEEDTUBE
QUICK OPENING VALVE
QUICK OPENING VALVE
TO PRESSURE GAGE
TO PRESSURE GAGE
A
A
SUPPORT
LIQUID OX. 4½ PINTS
GASOLINE 4½ PINTS
SUPPORT
TO REACTION GAGE
HYDRAULIC CYLINDER FOR THRUST MEASUREMENT
BASE
TOP SECTION A-A
© 1944 C.P. LENT.
ROCKET NO. 2 OF THE AMERICAN ROCKET SOCIETY 1932.
DRAWN BY: C. P. LENT.

FIG. 20

On the left is a successful design of a rocket built by the American Rocket Society. Note comparative sizes. The fuel cylinders have been constructed to hold two gallons of gasoline and a gallon of liquid oxygen. This rocket did weight 30 pounds and estimated reaction was 80 pounds. On the right is shown a simple experimental test stand built by the society to test the behavior of nozzles and motors. Each of the cylinders holds 4½ pints of gasoline and liquid oxygen respectively.

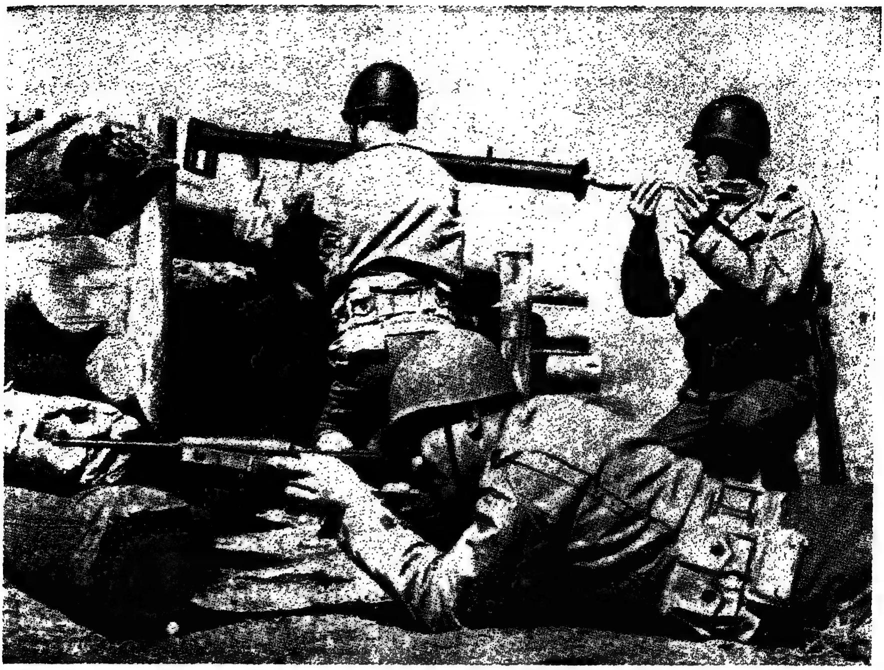


FIG. 19

A remarkable photograph of the Army's lightweight rocket tank blaster, the famous "BAZOOKA". The launching tube and the operating mechanism weight but 8 pounds. It has been reported that the cost for producing the gun runs only into a few dollars. The high speed rocket shell can pierce a four-inch armor plate and two feet of solid concrete. The tube is open at both ends and the gun is operated by a crew of two.

famous shot of July 17, 1929, at Worcester, Mass., was made with a secret fuel mixture of liquid oxygen and hydrogen. The fuel was exploded in an extremely rapid series of blasts, instead of continuously. Professor Oberth's "Baltic rocket", scheduled to be tried some time later, was powered by another secret mixture of liquid oxygen and hydrogen. He expected to attain a rocket speed of 12,000 feet per second. Oberth's second choice of a liquid fuel was ethyl alcohol and liquid oxygen. One advantage of alcohol is that it has a higher specific gravity than liquid hydrogen, and therefore does not require so large a container. Oberth's theoretical rocket, whose design and construction he supervised in minute detail was a step rocket employing alcohol as fuel for the first step and liquid hydrogen for the second.

Since liquid hydrogen and liquid oxygen bid fair to play an important role as rocket fuel it might be here well to recall briefly some data regarding their physical constants, methods of preparation, transportation and handling, and the nature of the reaction involved in their use. Hydrogen is converted into a colorless liquid at a temperature of —252 degrees C. Having a specific gravity of only .07 it is the lightest liquid known to chemists. Oxygen liquifies at a temperature of —181 degrees C. It is a mobile transparent, faintly blue liquid, having a specific gravity of 1.2. In the liquefaction of gases two problems are involved; cooling the gas to the necessary low temperature and insulating the resulting liquid against heat from the outside.

A better fuel than either alcohol or liquid hydrogen may well be the pure hydrocarbons. In comparing fuels as to

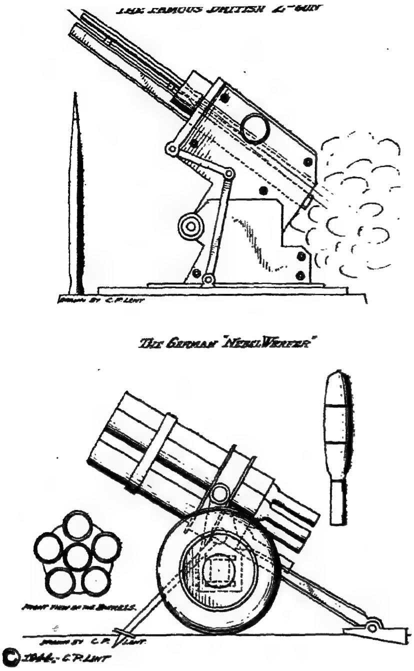


FIG. 21

Two interesting line-cut drawings of rocket guns. The one on the top is the famous British "Z-gun" which has been extensively used for the defense of London; note the size of the rocket shell in comparison with the gun. The one on bottom, is the German "Nebel Werfer". The latter is a multi-barrel gun and its shell is used to lay down a smoke barrage.

energy content the number of calories per unit volume of fuel is of much more significance in rocket construction and rocket efficiency, than the number of calories per unit weight. In general, the compounds rich in carbon prove superior to those rich in hydrogen, though the heating value per unit weight is higher for the latter. Accordingly benzol (benzene) is suggested as a fuel because of its high energy content per liter. Pure carbon itself would be the ideal substance, but since this does not occur in liquid form, it might be possible to use a mechanical mixture of finely divided carbon in its purest state, such as lampblack. This combination would form an especially efficient rocket fuel, perhaps the best possible as far as our present knowledge of substances extend.

Now as to the resistance problem. The resistance of the air was generally assumed to vary with the square of the velocity of an object passing through it. This is only roughly true even at ordinary velocities. At very low veloci-

long used to determine atmospheric resistance; or rather, since artillerymen are interested in how much the air slows up their shells, atmospheric retardation.

(vG)v (H)y
R equals.

where "v" is the velocity, "G" is a factor representing the tabulated retardation of a standard shell under normal firing conditions, the "H" function of "y" is a function of the height of the trajectory, and "C" is the ballistic coefficient. The results from this formula are subject to wide errors and would be most undependable for rocket firing at such velocities and for such distances as we are contemplating.

There is experimental evidence on air resistance for projectiles up to 16 inches in diameter and for muzzle velocities up to 3000 feet per second. But the curves ploted from this evidence and from formula are useless at high velocities and long ranges, as they are at very low velocities. When the Germans invented the long-range gun that fired on Paris from a distance of 75 miles they used both in determining the form of their projectile and the powder charge to dispatch it Both failed and they spent a whole year of experiment on the trial and error method of determining the charge. And their muzzle velocity was only 5300 feet per second—far less than the speeds we are contemplating.

The next problem is that of stabilization. I suppose one need not remind the reader than any projectile in flight, from a baseball to a bullet, is unstable along its vertical axis; that is, it tends to rotate in the plane of the horizontal or the transverse axis or both. These are inevitable small weight differences tending to pull the projectile out of its correct balance; the propelling force, applied at the base, exerts a powerful leverage and if the force is not applied directly at the axis point a certain proportion of it will go into the work of rotating the projectile. To overcome this, rifling was introduced. It imparted a rotary motion to the projectile which, besides its stabilizing gyroscopic effect, tended to smooth out inequalities in weight by bringing the heavier sectors into different positions at different times. Even in theory this would not grant our hypothetical rocket a high degree of stability, and in practice the rotary motion imparted by the rifling is not sufficient for its purpose.

Of course for a rocket the ballistic conditions are somewhat improved. We can place the explosion chamber, that is, the

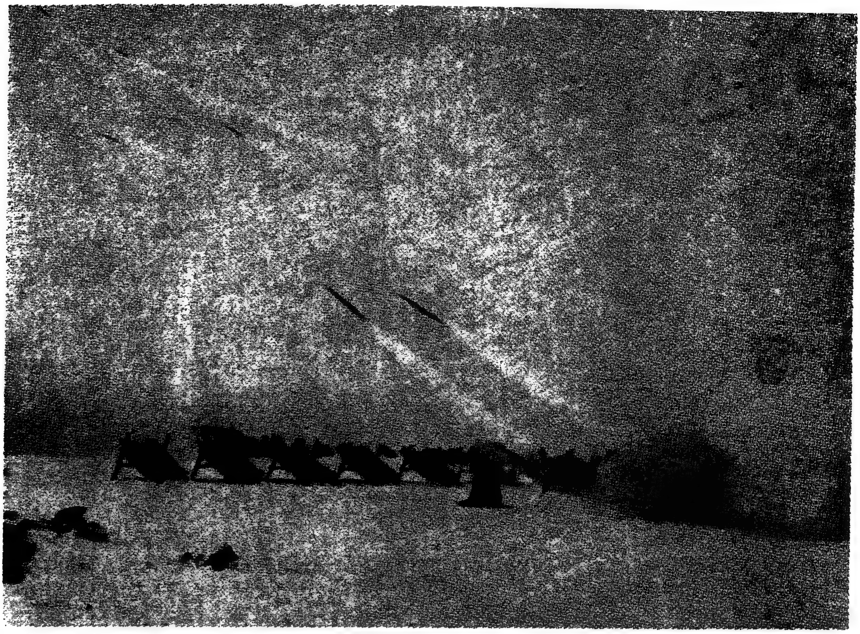
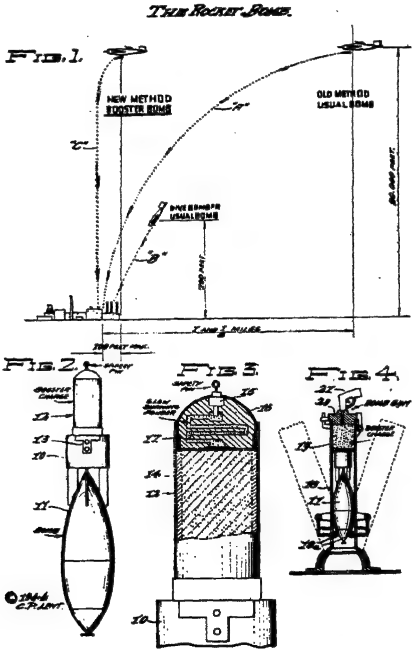


FIG. 21a

The famous Russian rocket gun "Katusha" shown in operation. It has been reported that volleys of high explosive rocket shells have been the main factor in the successful defense of Stalingrad and Leningrad.



THE ROCKET BOMB.
FIG. 1.
NEW METHOD
BOOSTER BOMB
OLD METHOD
USUAL BOMB
"C"
"A"
"B"
DIVE BOMBER
USUAL BOMB
200 FEET
20,000 FEET
1 AND 1/2 MILES
100 FEET MAX.
FIG. 2.
SAFETY PIN
BOOSTER CHARGE
12
13
10
11
BOMB
© 1944 C.P. LENT.
FIG. 3.
SAFETY PIN
15
16
SLOW BURNING POWDER
17
14
13
10
FIG. 4.
21
20
BOMB SIGHT
BOOSTER CHARGE
19
18
11

FIG. 22

An early rocket bomb design. Fig. 1 illustrates the difference between a standard bomb and rocket booster bomb. In Fig. 2 it can be seen that the booster charge is secured to the upper portion of the bomb. Fig. 3 is a cross section through the bomb. Fig. 4 is a novel design for a bomb gun. Note the trigger and the booster charge inside the gun.

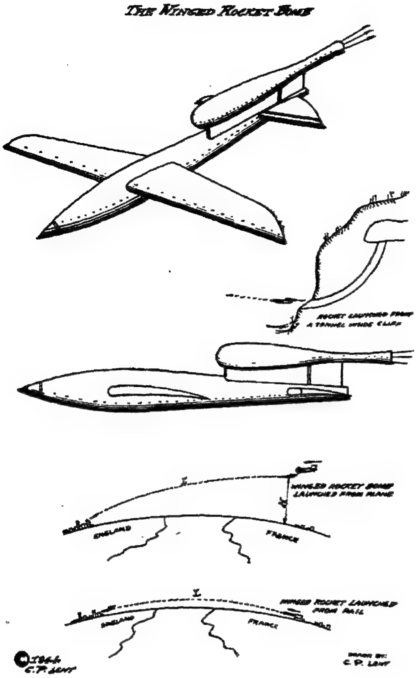

THE WINGED ROCKET BOMB
ROCKET LAUNCHED FROM A TUNNEL INSIDE CLIFF
WINGED ROCKET BOMB LAUNCHED FROM PLANE
ENGLAND
FRANCE
WINGED ROCKET LAUNCHED FROM RAIL
©1944 C.P. LENT
DRAWN BY: C.P. LENT

FIG. 23

The latest instrument of destruction, the "Robot Bomb" or "Winged Bomb". Note the reaction motor in the rear of the bomb and the wings in the front. Three possible ways for launching the bomb are shown. The bomb can be launched through a tunnel in the cliffs by the shore, or from airplanes flying above the target; also from a launching platform or rail.

propulsive force, nearer the center of gravity. In fact, it would seem essential that the explosion chamber include the center of gravity. But we are dealing with much longer ranges and higher velocities than anything encountered by military projectiles, which increases hugely the disturbing factor of air resistance. Unless our rocket were exquisitely balanced it would most certainly lack stability, which in turn, would throw it far off its course, for the instant our rocket departs from absolute stability in the line of its course, the acceleration we are giving it would drive is ever farther and farther from its destination.

Although a lot of private experimentation has been done bofer the start of the war, since then great strides have been made in the efficiency of liquid fuel motors and in the design of rocket and hot air, jet propelled planes. But most striking is the use of the reaction principle in the discharge of projectiles such as the Rocket Gun called "Bazooka" shown in Fig. 19, the famous British "Z-Gun" in Fig. 21 used for anti-aircraft work and the German "Nebel Werfer" The Russians also used a lot of rockets. The photo in Fig. 21a shows a rocket barrage.

But this is not all as in addition to such latest instruments of destruction as the "Rocket Bomb" shown in Fig. 22 and the "Robot Bomb" shown in Fig. 23 the rockets found other successful uses as in the anti-aircraft rockets shown in Figs. 24, 25 and 26. The former being anti-aircraft rockets used by the British Navy and the other an early design of Anti-Stuka gun by the author. Another, so-called secret weapon, is the rocket shown in Fig. 36, and the rocket torpedo, Fig. 34.

The incessant demands from commercial and military sources for more power for take-off has been a big factor in bringing about the modern high-powered airplane engine. This necessitated the controllable pitch propellor to efficiently utilize the added power at various altitudes.

The majority of large engines are supercharged to deliver maximum power for one minute periods during take-off. This time limit is imposed to prevent excessive cylinder temperatures and consequent burnouts. Use of this added power, in addition to a very drastic cleanup in external lines, has boosted wing loadings from the t15 lbs. per square foot of ten years ago to an average of 25 to 30 lbs. per square foot for today's big planes. It is interesting to note that Howard Hughes' Lockheed on taking off for his world flight had the unprecedented loading of 49 lbs. per square foot. Only when a ground speed of 125 M.P.H. had been reached at the end of one of the world's longest runways did it manage to stagge into the air.

To accelerate a plane from rest to its lifting speed the static thrust developed must overcome the retarding factors of wheel (or water) friction and air resistance. The former falls off as more and more of the weight is borne by the wings, while the latter rises. The greater the excess of thrust the higher will be the acceleration rate and the shorter and more rapid the take-off.

Not only is take-off performance important in relation to the plane's payload and range but it is of great significance in determining the size and cost of modern airports. Huge airports near large cities, such as the new field at North Beach, N.Y.C. with its 6,000 foot main runway, are tremendously costly to construct and maintain. This has a direct bearing on the cost of transport operation as high fees must be paid by the airlines.

Under wartime conditions small emergency fields must often be pressed into

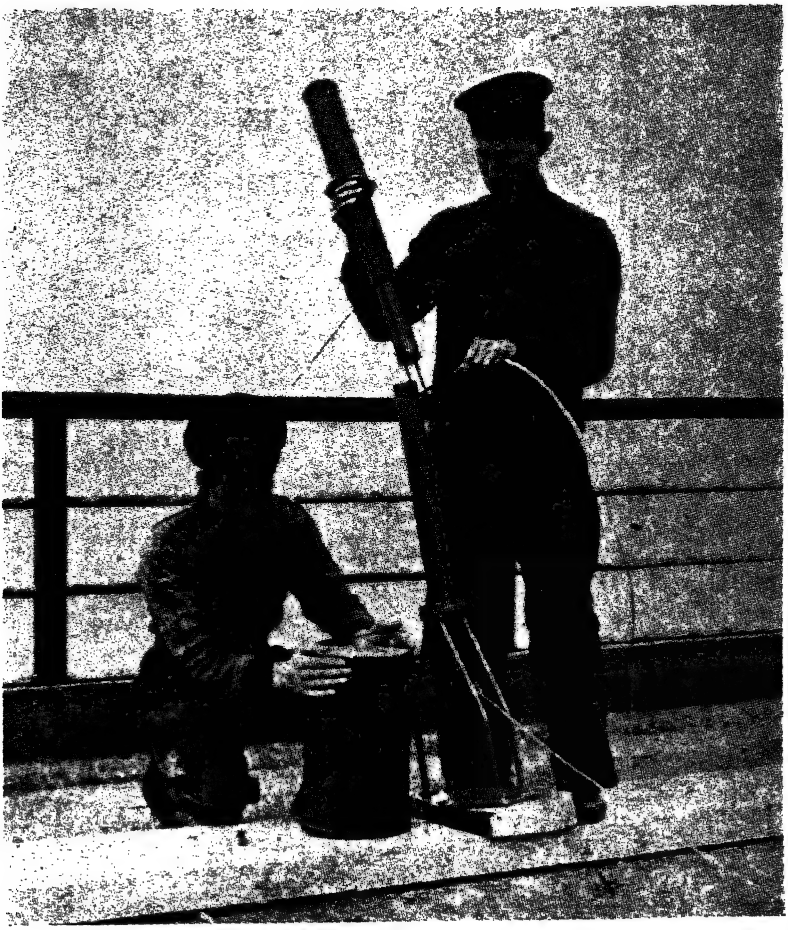


FIG. 24
A so-called "Snare Rocket" used by the British Navy for anti-aircraft defense. Note the drum for the flexible wire beside the launching gun. One end of the wire being attached to the rocket, the other to a wire spool in the drum. Also note the firing cord.

service. Heavy planes would have to whittle their loads unless assisted at take-off. In this case the higher acceleration imparted by added power would be utilized in getting the normal load off the ground in a shorter run. For use on large fields the load could be greatly increased and the standard length run retained.

To avoid the limitation imposed by airport runway lengths designers of large, aircraft have in some cases turned to the flying boat and seaplane types to take advantage of the longer surfaces of bays and sounds. Unfortunately water drag is much higher that wheel friction so that

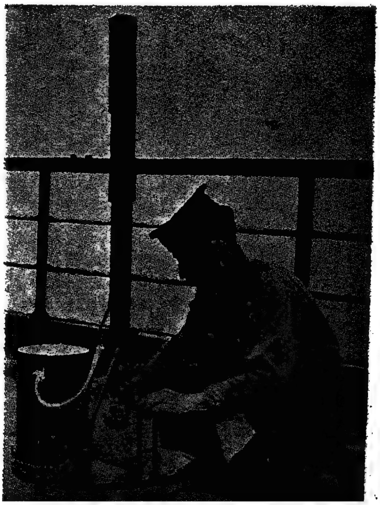


FIG. 25
The "Snare Rocket" ready for firing. Note the simple launching device.

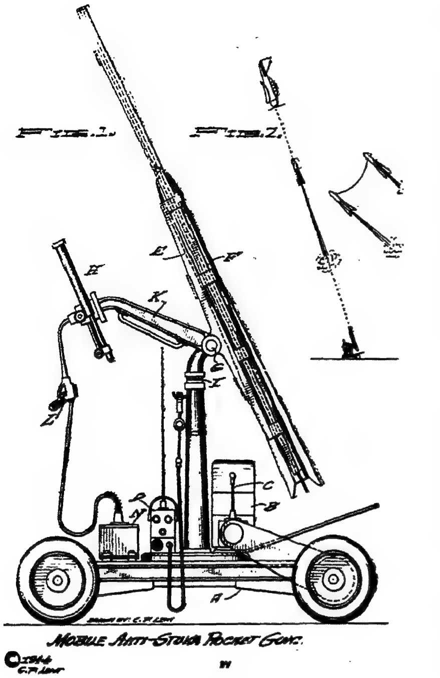


FIG. 26

An early design of a mobile anti-aircraft gun. Note the wheeled chassis upon which the gun is mounted, also the sight tube and the revolver-like trigger for firing the gun. Fig. 1 shows the general assembly of the gun while Fig. 2 illustrates the manner the gun is used against dive bomber attacks. Referring to the figures (A) is the chassis of the gun proper; (B) the gasoline motor for driving the gun; (C) the driving stick; (D) the short wave receiver; (E) the launching rack; (F) the rocket; (G) the hinge for tilting the launching rack E; (H) is the telescope sight; (I) is a swivel for rotating the gun; (J) the arm sight, and (L) the revolver trigger for firing the rocket electrically by remote control.

the accelerating rate is even lower and a corresponding longer run is necessary before the plane will lift. Hazard is also increased by the chance of upsetting in rough water, hitting of driftwood or small boats, as has happened several times in the ocean crossing trials. Another objection is the increased air resistance of flying boats and seaplanes over lond planes of equal capacity, due to the marine nature of their hulls or floats. Most designers are inclined to the belief that the land planes will eventually replace flying boats even in transoceanic travel.

To date the only method of external assistance to prove its merit in continuous service is the ship catapult. Indispensable for many years to the world's battle fleets there has lately been a trend to its use for commercial purposes. Mail service from ship to shore can be expedited in this manner as has been shown in trials.

The methodical series of ocean mail flights by the Deutsche Luft Hansa before the war's outbreak, marked the most ambitious use of the ship catapult. The equipment used on the midway ship "Friesenland" was capable of launching planes up to 37,0000 pounds gross weight. The size of the four-motored "Nordwind" and "Nordmeer" indicated the power of this accelerator. While an excellent means of mail transport with trained crews, the high acceleration factor of 2 to 2½ G rules this means out for passenger service.

A land catapult was used by the Wright brothers in the first powered flight. Today some recommend a return to this method for getting heavy planes into the air. The Royal Aeronautical Establishment some years ago undertook a research program at Farnsboro using land catapults or eccelerators for launching military planes. A telescoping cylinder arrangement with direct thrust was used in some trials. More practical and less strenuous was a method using a cable and trolley to which the plane's tail was fastened. The cable was wound around a drum powered by 2 compressed air engines. It ran from the drum to a pulled fixed into the field then back to the tail trolley. Planes up to 18000 pounds weight lifted in a 120 foot run under 1 G. acceleration, yet the method was never put into service.

An unusual and spectacular attack on the problem was Major R. H. Mayo's composite aircraft, popularly known as the "Pick-a-back plane". Taking off from the water unaided the upper component range was limited to 1500 miles. When released at 5000 feet by the powerful mother plane this range increased to 3500-4000 miles. Despite a successful round trip across the Atlantic this method does not appear to be acceptable as a solution. The main drawbacks are the high cost of the parent planes, the need for a heavy crane to lift the upper ship in place, a locality with quiet water to prevent damage in joining, and the necessity for great skill when separating in the air.

As a plane can fly with a much greater load than it can lift off the ground the possibility of fueling while in flight has often been considered as a means of reducing take-off loads. Present equipment have transfer rates as high as 80 gallons per minute. This method is well suited to individual record-breaking flights, but is hardly practicable for large scale operations. A fleet of refueling planes and

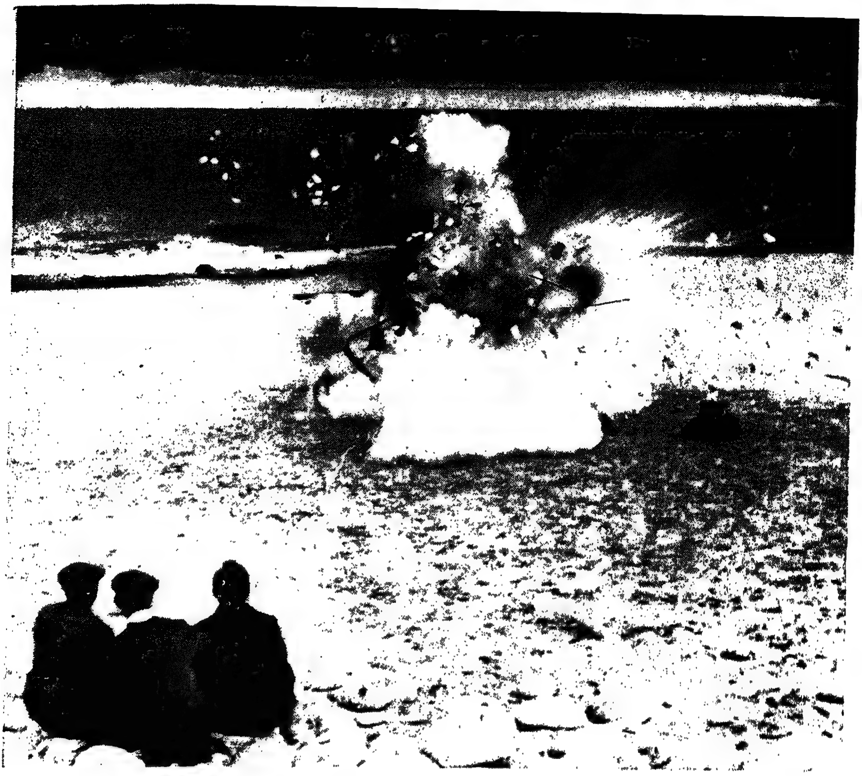


FIG. 27

A remarkable photograph showing one of the Tilling rockets exploding. Note that the spectators are sitting unprotected. This explains the heavy toll of accidents by the early experimenters.

their trained crews would not only be costly, but would clutter up the air around airports where frequent schedules are maintained. It is obvious that a formation of bombers would be very difficult to fuel up in this manner.

The Junkers plant at Dessau, Germany, conducted tests with a heavily loaded seaplane of the Ju 33 type, during 1929, using a number of powder rockets to assist the take-off. Clipped to the under surface of the wings, the cartridges were dropped off after they had helped lift the plane into the air. Official word of the tests claimed them "successful and very promising" but no further trials were ever reported. Much ado was med in the newspapers and popular magazines about a number of flights powered by several powder rockets. These were nothing but stunt flights and of questionable value scientifically as little if any data was ever published. (See Fig. 28).

The future of rocket power, of course, lies not in these crude unstable powder rockets, but in the much more powerful, controllable, liquid fuel motors such as have been tested by the American Rocket Society, Goddard, Sanger, Valier and Heylandt, the German Rocket Society and others.

The initial goal of serious rocket experimenters both here and abroad has been the development of a meteorological rocket to replace the sounding balloon now used for gathering weather data. A motor thrust of 100 to 200 lbs. was considered sufficient for this purpose and the units so far tested have been quite small.

After making several trial flights of liquid fuel rockets, each of which ended prematurely in mishap, the Experimental Committee of the American Rocket Society decided to confine its efforts to proving stand tests until greater motor dependability had been achieved. The resultant program of research, while only scratching the surface due to scarcity of funds and facilities, is the only dependable source of information available on rocket motor performance.

Outstanding among the facts so far unearther is this: present day motors

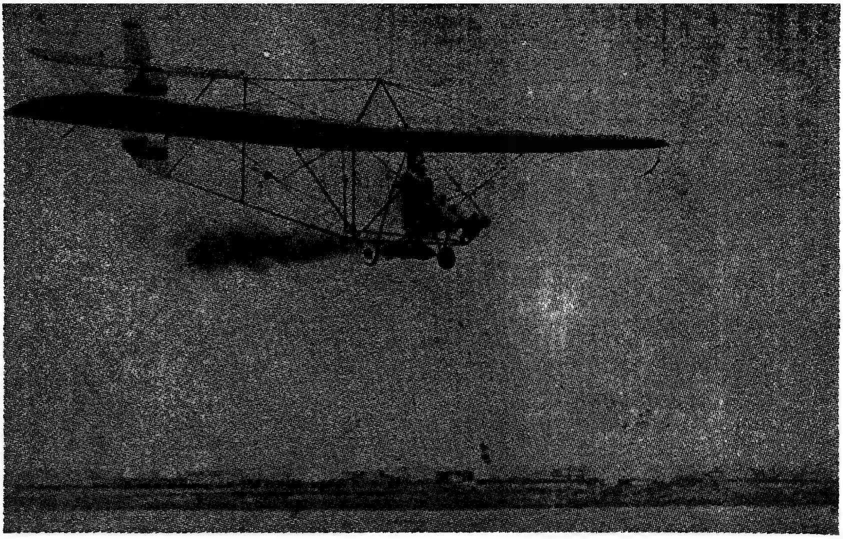


FIG. 28
One of the first rocket propelled planes: It utilized gun-powder rockets mounted under the chassis and was launched like a glider.

burning ethyl alcohol and liquid oxygen can produce a thrust of 200 lbs. for each lb. of combined fuels consumed.

The best powder rockets obtainable give a thrust ratio of about 50 lbs. per lb. of powder consumed, and have the great disadvantage of being absolutely uncontrollable while burning. The duration of their thrust period is usually only a second or two.

It is obvious from this that loose talk of rocket planes will have to be grounded until the 200 : 1 ratio is increased tremendously.

At the present efficiency a motor of even 1000 lbs. thrust would consume 5 lbs. of propellants per second, 300 lbs. per minute and 18,000 lbs. in an hour's flight. Nonetheless the extreme lightness of the motor in relation to its power output, its evident low initial and maintenance costs, and the simple equipment necessary for its operation suggests that the present motors are not to be ignored in the attack on the problem of take-off.

During the take-off run a high powered airplane engine, geared down and equipped with a constant speed propeller, develops approximately 4 lbs. thrust per horsepower. Under normal conditions there is a tendency for this thrust to decrease in direct linear relationship to the speed increase, however the figure of 4 lbs. may be taken as a reasonably correct average for modern planes. Totaling the weight of the engine and propeller results in a figure of from 2½ to 3 lbs. thrust per lb. of powerplant. Contrasted with this our experiments indicate large rocket motors should easily yield 50 lbs. thrust per lb. of motor weight. In addition the static thrust of the jet will have a tenency to increase with speed.

By moving a large mass of air backward at comparatively low speed the propeller method shows a much higher thrust return per lb. of fuel consumed than does the rocket jet. The latter in exhausting a small mass backward at very high speed loses over 90 per cent of its kinetic energy to the surrounding air. Since jet velocity must be as high as possible this shock loss can be partly overcome by accelerating the air which is to come into contact with the jet gases, by utilizing a Venturi cone surrounding the motor. N.A.C.A. research indicates possibilities of increasing thrust from 10 per cent to 50 per cent by using such an augmentor.

Work is now under way on a motor considerably larger than any so far tested which is to utilize this Venturi principle. Not only is thrust augmentation planned but the large quantities of air sucked in by the jet will pass over longitudinal cooling fins covering the motor and nozzle. But this method a simple and reliable cooling action is expected. Unlike other engines where the cylinder temperature must be kept low to prevent burning of the lubricating oil, preignition and seizing of parts, the temperature of

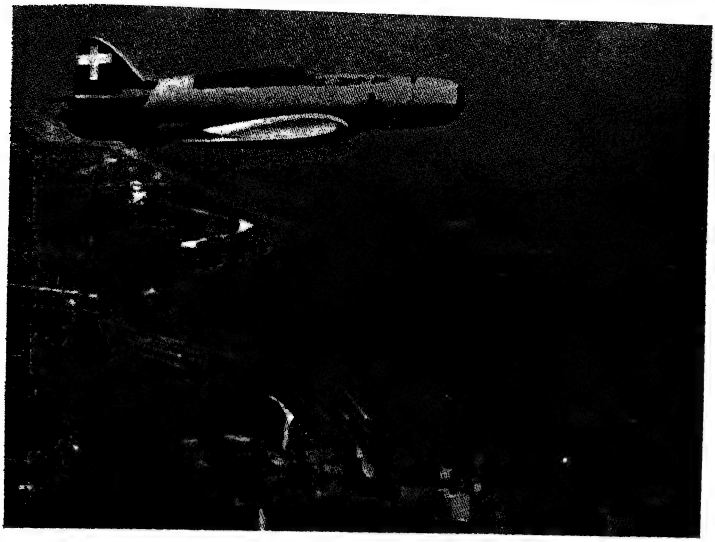


FIG. 29

Above is shown a remarkable photograph of the Italian Caproni-Campini CC2 jet-propulsion plane. Note the streamlined design and the absence of propellers.

the rocket motor is limited only by the melting point and hot strength of the materials of which it is constructed. It is reasonable to believe the air cooling action will prevent burnouts during the brief time the motor will be called on to function.

Reluctant to depart too far from convention many approaching the subject of rocketry have asked, "Why not use the free surrounding air for burning the fuel?" Experiments with gasoline turbines and mathematical investigation by the N.A.C.A. and others have shown that this is possible. The recent report of the British air driven plane illustrates the possibilities of this type of propulsion. The Capriny jet propelled plane shown in Fig. 29 is another example of application of the hot air jet principle for planes.

The unanimous opinion of serious experimenters is that the oxidizing agent should be carried in the most compact form available—liquid oxygen. This substance, which boils off at temperatures above —182.5°C, presented several difficulties of usage when obtained for the preliminary experiments. Therefore they have developed a technique of handling, storage, pouring, pressure feed, etc., which greatly increase its practicability.

As ethyl alcohol requires 2½ times its weight of oxygen for combustion it is easily seen that the price of oxygen will be the major factor in a cost analysis of rocket operation. At present the liquid is not readily available in all localities and cost will vary with accessibility. In the New York area it is obtainable for about 10 cent per lb. When the demand increases it should sell for about one-half this figure. Present manufacturing cost is only about ½ cent per lb.

Gasoline, used by Goddard and by the American Rocket Society in its early tests, requires 3½ times its weight of oxygen and is thus a more expensive fuel and only slightly more powerful per pound of mixture.

Paying about 5 cents per lb. for alcohol and 10 cents per lb. of oxygen brings a lb. of the mixture to 8½ cents. A motor with present 200 : 1 ratio would consume 5 lbs. of propellants per second per 1000 lbs. thrust. Each 1000 lbs. for 20 seconds take off would now cost $8.50 in fuel, when demand increases this should drop to $5.00 per 1000 lbs.

A large rocket motor mounted in the tail, or several smaller ones installed in the trailing edges of the wing, should not present any intricate problem of redesign. Stress analysis and redistribution of weight will be necessary of course. The greater part of the weight of such an arrangement would be in the fuel which would be consumed during the take-off run, leaving the light motor and tanks as the only objects to be carried. Before a detailed mathematical analysis of such an installation can be made, test stand performance figures of a large motor will be necessary.

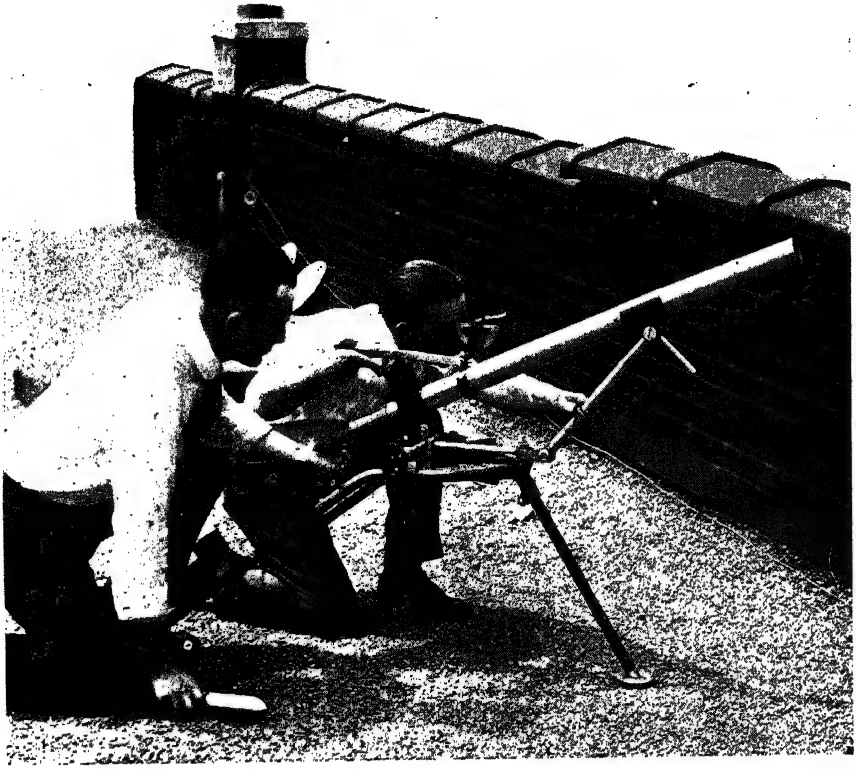


FIG. 30
A study of an early rocket gun built by the members of the A.R.S. It was mounted on a tripod and was built to fire 2-inch rocket shells.

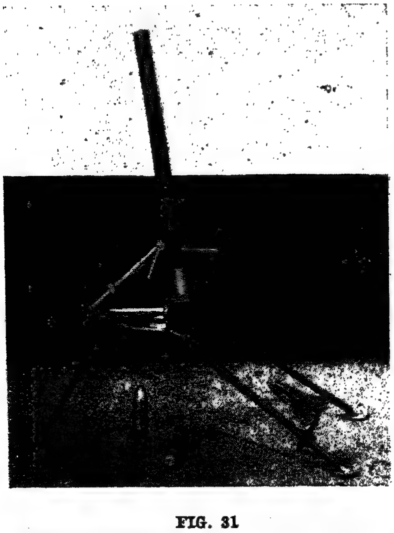


FIG. 31
Another interesting photograph of the rocket gun showing the launching tube raised nearly perpendicularly. Note the size of the rocket shells in comparison with the gun.

It is a sad commentary on human nature that the rocket, only recently thought of as a means for transportation is now used as an instrument of destruction.

The sincerity of those proposing its use as a means of national defense cannot be questioned, but, they must realize that it has been repeatedly demonstrated in this current war that so-called defensive weapons can easily be adopted to offensive. German Panzer columns in the Battles of Flanders and France used anti-aircraft guns to shoot down defending bombers; pursuit planes developed for defense are being used as bomber escorts and light bombers; commercial planes carry parachute troops and defensive rockets are adapted to the offen-

A number of active military uses for rocket power had been suggested before the war and are being used at present, among them being.

1. Huge rocket-projectiles to outdistance present artillery.
2. Anti-aircraft shells to be shot from the ground and attracted to the bomber by sonic or electrical effects.
3. Rocket powered bombs shot downward at ground objectives, improving accuracy.
4. Military meteorological rockets to check weather conditions preceding mass bombing flights, gas attacks, etc.
5. As a means of assisting bomber take-off or interceptor climb.
6. Rocket shells for aerial combat.

As we have seen rocket projectiles are far from new. Back in 1806 the Emperor Napoleon had gathered his legions at Boulogne for an attempt to invade England. The newly invented Congreve rocket played a large part in the smashing of his flatboat armada. Their use in that war, as well as in the War of 1812 and our Civil War have been well-covered. Enough to point out that rocket-projectiles were made obsolete by the development of cannon artillery which proved immeasurably superior in range and accuracy.

In recent years, with the advent of the liquid-fuel rocket motor, innumerable prophecies have been written of the coming use of rocket shells raining death on cities 500 miles distant. But the "next war" is here and nothing of the sort has occurred. The greatest range for such rockets being 200 miles.

The anti-aircraft ground launched rocket, with sonic-hunting control, has also been much talked about for the last 20 years, but little has been done to realize it. Every so often one reads in the newspapers of some obscure inventor having developed something along this line, but these do not appear to ever get beyond the wooden model stage, although the Germans are believed to have used such a rocket quite recently.

Now the emphasis appears to be on the rocket-shell fired from defending planes at bombers, the idea being to project a shell larger than is now possible from existing aerial weapons.

During the early days of World War I many planes went aloft armed with rockets. There were rather crude powder weapons, attached to struts and nacelles, meant to be used against observation balloons and Zeppelins. Many of the smaller gas bags went down in flames after being pierced by a hissing rocket but no Zeppelin is known to have fallen to this weapon. Before long the more efficient incendiary machine gun bullets replaced the often erratic rockets.

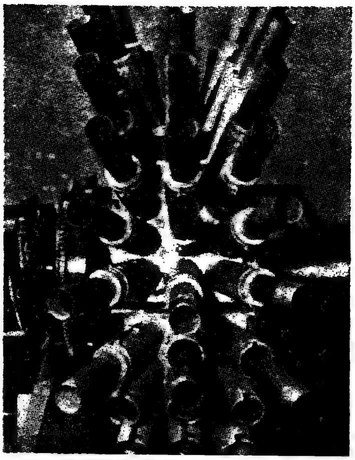


FIG. 32

A Russian Multi-tube gun of the type used to fire rocket shells. It has been reported that this gun was a part of the equipment of a Russian pursuit plane, although it could just as well be used as an anti-aircraft gun. The launching tubes seem to be mounted upon an axially rotatable platform.

Since the termination of the last slaughter enormous quantities of mathematics, much thought and some serious experimental research have been devoted to advancing the science of jet propulsion. It is only natural that this type power, really efficient only at high velocity, should be called into use, in the new terrific speeds of aerial warfare. For rockets launched from planes see Fig. 93.

Sky battles have undergone quite a change since the days of the Aces. The speed of the machines has tripled and the complicated combat maneuvers have vanished with the Spads and Fokkers. Physiological strains rule out violent aerobatics at today's speeds. The only method of attack possible is a quick dash at the enemy, a wide turn and another dash. With the range of the best modern weapons limited to 500 yards with accuracy, and the velocity of planes now well over 350 m.p.h., the opponent can only be kept in the sights for 3 or 4 seconds at most. During this short time as much destruction as possible must be launched in his direction. Before we can consider the potentialities of the rocket-shell in this game of tage it will be necessary to evaluate current methods.

To suit these new conditions Britain went in for quantity of armament. The

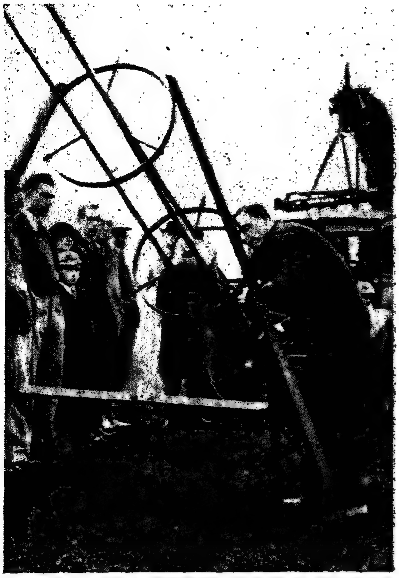


FIG. 33

An interesting photograph of a German rocket by Gerbard Tucker. Note the elaborate construction of the launching rack which in this case seems to be inclined in an angle of 45 degrees from the horizontal.

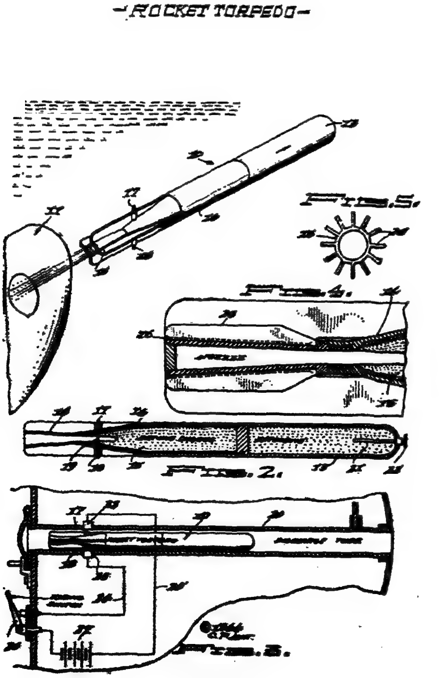


FIG. 34
An interesting study of a rocket torpedo. In Fig. 1 one can see the torpedo leaving the discharge tube of the submarine aimed at the objective. Fig. 2 is a cross-section through the torpedo, the forward end contains the explosives and the read the driving charge, nozzle, and the electric ignition. In Fig. 3 the torpedo is shown in the discharge tube ready for firing. Note the electric wiring for the ignition. Figures 4 and 5 are details of the nozzle.

sleek Spitfires and Hurricanes that threw back to Nazi onslaught were each armed with 8 rifle-calibre machine guns. These 303 caliber Brownings each fire 20 rounds per second, mass production in death. A raiding Heinkel or Dornier can be blasted with our 500 slugs (each over an inch long by 5/16" in diameter) in one brief volley. Limited by the ammunition load of 600 rounds per gun, the British fighters can only make a dozen or less attacks before descending to re-load.

German fighters escorting the bombers are armed with 20 and 23 mm aerial cannon as well as numerous machine guns for closer work. The Nazis have gone in heavily for quality of fire power and all the swastikered swarm, from single seater fighters to heaviest bomber, bristle with these miniature artillery. One hit by their high explosive shells on the wing or fuselage of a British fighter means another statistic in the report of the battle

While airplane cannon saw limited use in World War I, notably by the French Ace Georges Guynemer, it was at that time an awkward, heavy and cumbersome weapon to use. In recent years the Swiss Oerlikon Machine Tool Co. has successfully revived the aerial cannon, and various models of their gun are in wide use today.

Originally developed as a 20 mm weapon for flexible use in the nose of bombers, they showed so much promise that they were soon adapted to lighter installations. In some cases they are wing mounted, in pursuits with liquid cooled engines they fire through the hollow propeller shaft, which is geared off the engine. The famed Messerschmidt 109 has this installation in some models, in others two are wing mounted and machine guns fire through the whirling propeller blades.

It is considered too hazardous to attempt synchronizing these shell guns with the propeller for should a shell hit a blade it would easily blow it off whereas a machine gun bullet will cause only minor damage. Thus, as will be the case with rocket shells, all aerial cannon either fire through the prop hub or outside the propeller disc.

Many of the French fighting planes were equipped with a version of the FF Oerlikon gun, manufactured by the Hispano-

Suiza Works under the license. This famed engine firm took the original design of the FF and modified it to suit their engine, building it as part of the Powerplant and so arranged as to fire through a hollow propeller shaft.

The Danish Madson air cannon, manufactured by the Danski Industrial Syndicate of Copenhagen, was used by the short-lived air forces of Belgium and the Netherlands. This weapon comes in a number of sizes, the 20 and 23 mm models being of the same weight and general dimensions. The 23 mm gun weighs approximately 11 5lbs., fires 20 shells in 3 seconds or 360 to 400 per minute, and has a muzzle velocity of 2394 fe./sec. With a four foot barrel this gun is aircooled and works similar to a Browning machine gun. When belt fed a supply of 100 rounds weighs 80 lbs. with links. Interesting is the total recoil of the gun with a single shot it is about 3000 lbs. during automatic firing it may reach 3600 lbs. Very little of this is transmitted to the plane's frame for it is absorbed by a muzzle buffer and the recoil arm and spring which feed in the next shot and fire it. By an ironic quirk of fate many of the planes armed with these guns which rose to battle the Luftwaffe were creations of the late Anthony Fokker.

The deadlines of the aerial cannon has aroused the British and all late models of their fighters, including those bought from the U. S., are being armed with cannon as well as machine guns. The Vickers-Armstrong cannon is said to be mounted in the Spitfire III, the Hawker Tornado (new version of the Hurricane), Boulton Paul Defiant, Westland Whirlwind and Fairey Fulmar.

In these United States the war in the air is being closely watched and the aerial cannon's place in combat is one of the lessons learned. Recently a very large order for airplane shell guns was issued to the Munitions Manufacturing Corp. Practically all new military planes are being made to carry one or more of these weapons. Specifications are not yet available.

The American Armament Co. has been hard at work for some years on a 37 mm cannon, but it seems that all the "bugs" have not been worked out of this gun and few if any planes have it installed.

Much larger than the European guns this throws a 1.1 lb explosive shell. Details are available on 2 barrel lengths, the 20 caliber and 50 caliber, the former for defensive use has a range limited to 1800 feet and a muzzle velocity of only 1250 ft./sec. This weapon has a weight, mounted, of 250 lbs. This high weight and short range are a disadvantage. To overcome this the offensive gun, with a 6'8½" barrel, has been designed with velocity of 2700 feet and range of 3500 feet. But this gun weighs 440 lbs. without a mount and being so cumbersome can only be lugged along by heavy bombers.

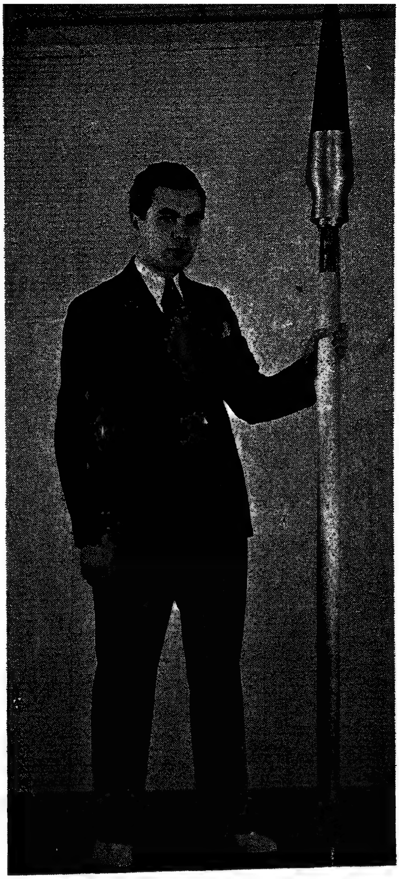


FIG. 35

An interesting design of a tandem cylinder rocket built by the writer. This rocket is called the spear or arrow rocket due to its spear-shaped design. For a cross-section through the motor see Fig. 56, page 56 and Fig. 70a, page 70.

The 37 mm shells are fed in clips of 5 weighing 8 lbs., and can be fired in 30 seconds. They come in high explosive, armour piercing, super high explosive and cannister for use against troops. Like the Oerlikon the shell is bore safe, an offset detonating the pin does not come into line until clear of the barrel under centrifugal force of rotation. If 200 shells are carried this will add 350 lbs. more to the weight of armament, which is rather high. While this gun has many

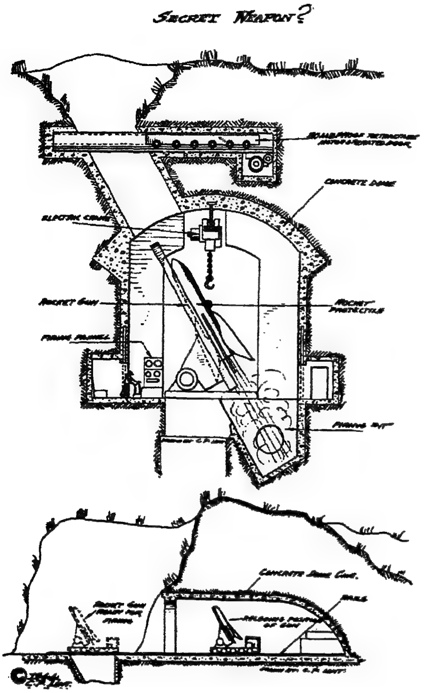


FIG. 36

Is this the long talked of secret weapon? The upper cut is a huge long range rocket shown upon its launching rack in a specially constructed concrete implacement deep in the ground. The bottom view is presumably a deep cave near the coast from which rockets can be launched. Notice that the rocket gun is mounted on wheels and is wheeled outside of the cave for firing.

disadvantages yet to be worked out, it is a very powerful weapon.

While the much vaunted British 8 gun fighters have received a great amount of publicity, it is apparent that they were not found the ultimate solution in armament. For the English are switching over to the Nazi bag of tricks and installing aerial cannon and the larger .50 caliber machine guns in their newest planes. These .50 caliber and its cousin the 13.2 mm gun spew forth 600 slugs pr/min (each 2⅜" long by ½" diameter, weighing about 1¾ oz.) of several varieties.

That the present weapons are quite deadly daily claims and counter-claims attest. But man has never been satisfied with his toys of destruction and the thought of a rocket-projectile offers his curiosity a new plaything.

Though the recoil load of the heaviest guns now used can be borne by a small fighter, by clever absorption of the reaction, it seems that guns firing shells of say 75 mm size will be borne only by heavy bombers or big destroyers of the air. The problem is to increase the effectiveness of the small bombers, to improve the efficiency of the defensive air force.

As has been pointed out the reaction from a rocket shell launched from a plane would be practically negligible, so that even small pursuits could fire shells of 3" or more. Unfortunately there are many difficulties connected with utilizing jet propulsion in this manner. Although lately many of these difficulties have been overcome and many planes had been equipped with rocket projectiles fired from racks under the wings of the craft. (see Fig. 93).

The machine guns fire a stream of bullets, we try to spray our opponent with this stream. With the 20 mm cannon we are still using a stream, not as solid as the machine gun's, but of much greater power. The 37 mm gun must be thought of as firing single shots even if comparatively closely spaced. But with a rocket-firing plane, as used, the shells are few and far between, each shot is an individual attempt to destroy the enemy. We are "putting all our eggs in one basket" and depending on accuracy of aim.

For any conceivable use in aerial war the liquid-fuel rocket motor, fed through an intricate induction system, with attendant difficulties of fueling etc., is out of the question as power-plant for a shell of the type considered. Therefore we must backslide to the use of the now scorned powder fuels, thus losing all the benefits gained in the last 10 years of experimental research. True, there are many powerful dry fuels which might be used, but none as powerful as the liquids currently used in experimental work.

Another design that does seem to offer more promise is a shell fired from a gun with rocket propulsion to give it a constant velocity and longer accurate range. Thus the initial velocity could be kept comparatively low, say 1500 ft./sec., over a long distance this would be made up for by constant or even increasing velocity. With such a low initial velocity we could fire a much larger shell with no more recoil than is now given by smaller shells with higher muzzle velocity.

Ending this chapter let us hope that in the near future Rocketry will find a better field of operation than the present one of destruction and that some day one might travel by means of rocket propelled craft not alone upon this earth but also to the distant planets thus to fulfill the greatest dreams of them all—Interplanetary Travel.

BAZOOKA

Resemblance to comedian Bob Burns' musical instrument, the famous bazooka, inspired the name of this newest weapon of destruction.

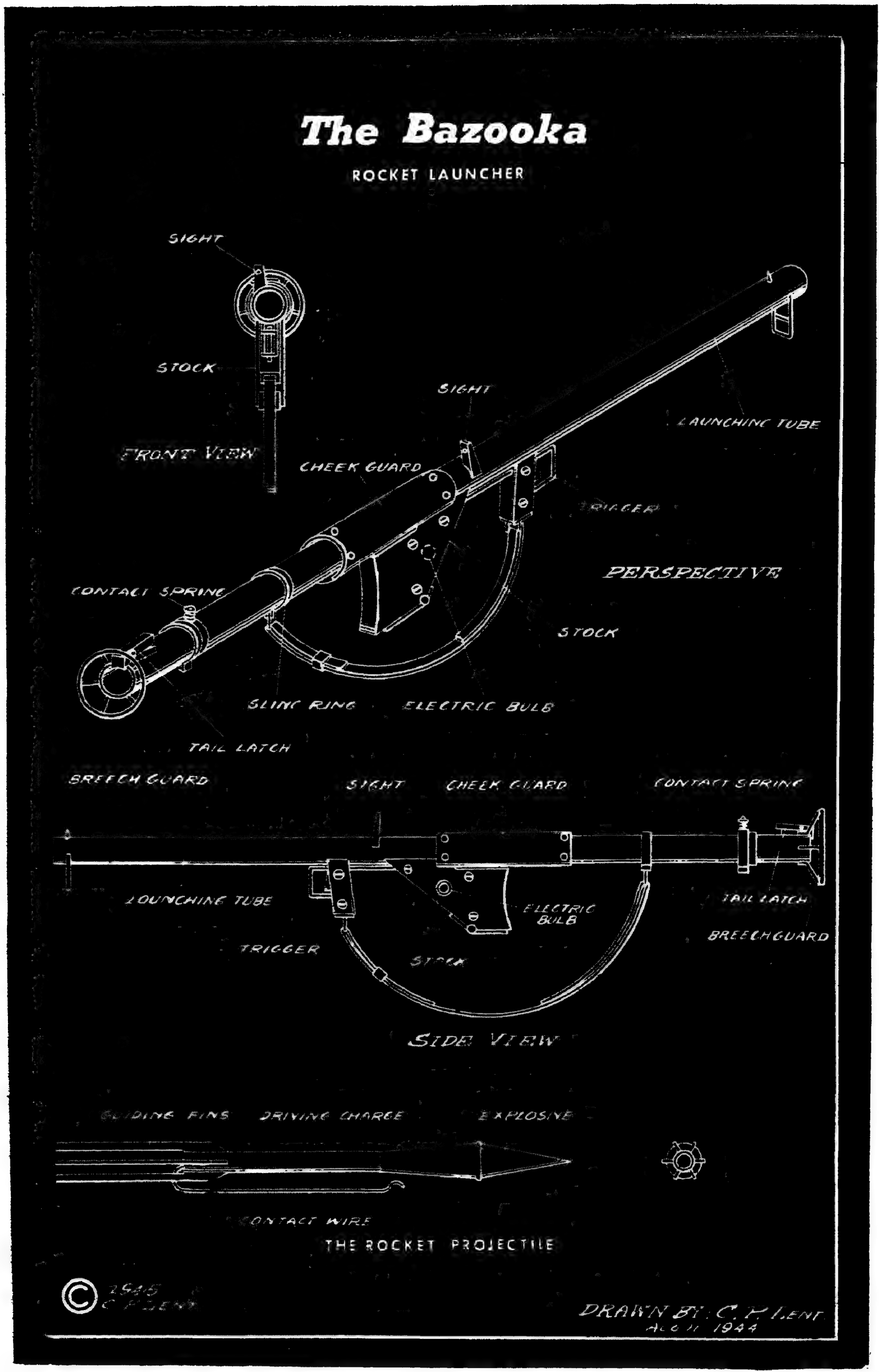
By developing the bazooka rocket gun, the Ordnance Department not only modernized an old and almost forgotten weapon, but literally discovered the only effective means for defense against the tank. Although rocket guns date back to 1800 when the British Fleet used them in Baltimore Harbor under the name of "Congreve Rocket", bazookas eventually will make the tank obsolete as an effective weapon of attack in future wars.

The whole thing is a very simple device and mainly consists of two parts, the launcher and the shell. The launcher comprises a metal tube several feet in length and from 2″ to 3″ inside diameter. It is open at both ends, the front having the sight and the face guard to protect the user against the blast of the exhaust gasses of the rocket shell, and in the it has a metal breech guard to help insert the projectile into the tube. Halfway in between, there is a wooden stock which the firer places against his shoulder when discharging the gun. Ahead of this is a fore grip which carries the trigger and which is held with both hands to facilitate aiming. An electric battery is located within the wooden stock and is wired to a small electric bulb visible on the outside of the stock. The latter is connected to a switch which is operated by the trigger and also to a wire leading from the battery towards the rear of the bazooka.

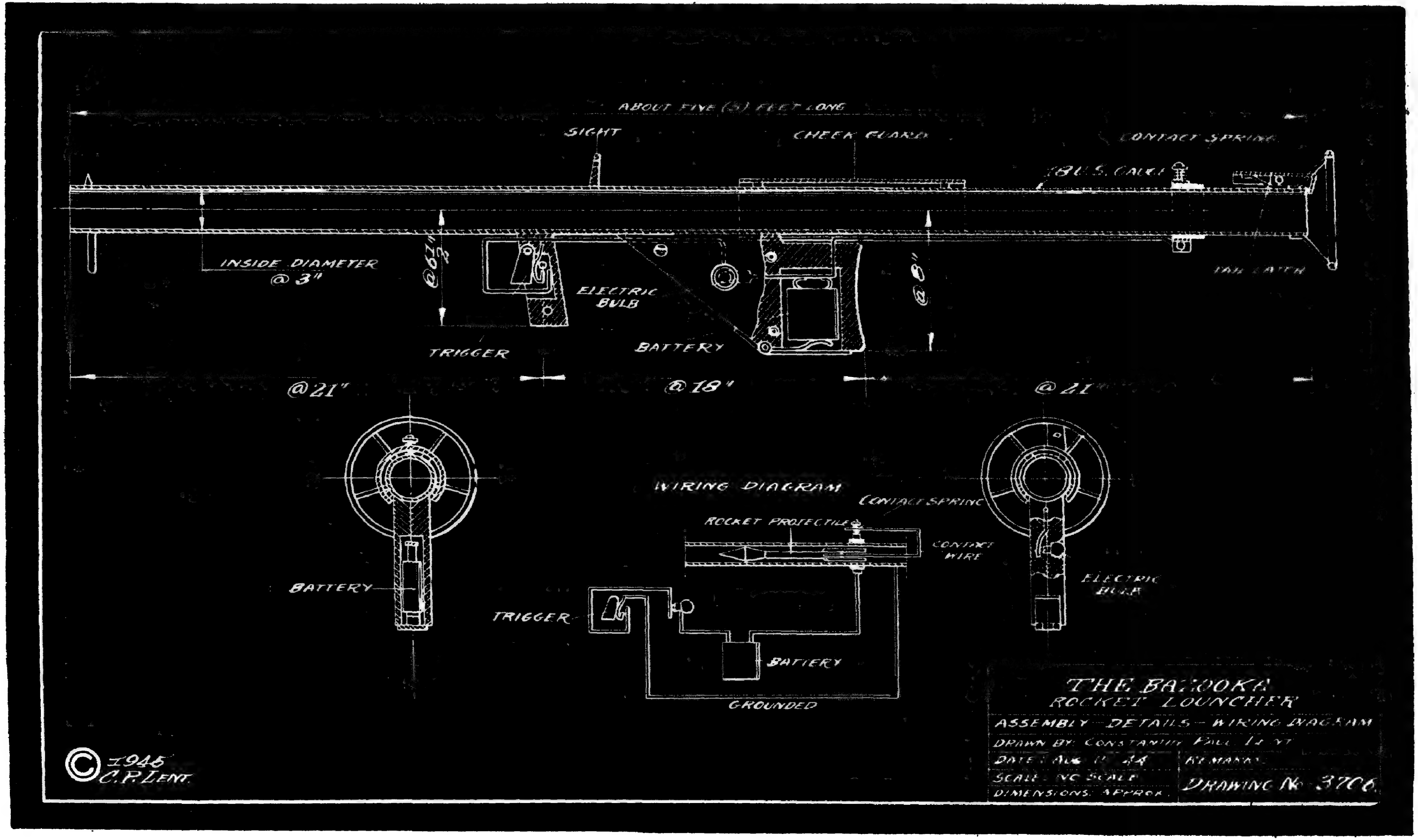
The rocket shell proper consists of the explosive charge in the head of the projectile and of the driving charge in the rear with a number of fins to guide it in flight. The driving charge has an igniter which is set off electrically, and for that purpose a length of electric wire hangs from the rear of the projectile. To fire the gun, the projectile is loaded from the back of the tube and the hanging wire is connected to a contact near the rear of the bazooka. The contact is a part of the electric wire leading from the battery. Although the bazooka is loaded and fired by a team of two men, it can also be operated by one man in an emergency. Before inserting the projectile within the tube, the gunner presses the trigger to make sure that there is no short circuit and watches the bulb to see if it flashes. If it does not flash, it is safe to load the gun.

When the bazooka is fired, that means when the trigger is pressed by the gunner, an electric circuit is closed from the battery to the bulb, then through the wire leading to the rear of the bazooka and from there to the driving charge of the projectile. The body of the rocket shell contacting the inner walls of the tube represents the ground connection, thus closing a complete electric circuit. The effect of the erplosion when the rocket hits the target is tremendous. Its force can knock out the heaviest tank with a single shot. It can penetrate three feet of concrete and sometimes it wrecks entire walls in large buildings.

In the rear of the bazooka, there is a tail latch which prevents the rocket shell from accidently falling off the tube. If it is necessary to remove the rocket shell, the tail latch is pressed and the shell is taken out, after first replacing the safety pin in its original position. The pin must be removed prior to placing the shell into the tube for firing.


The Bazooka
ROCKET LAUNCHER
SIGHT
STOCK
FRONT VIEW
SIGHT
LAUNCHING TUBE
CHEEK GUARD
TRIGGER
PERSPECTIVE
CONTACT SPRING
STOCK
SLING RING
ELECTRIC BULB
TAIL LATCH
BREECH GUARD
SIGHT
CHEEK GUARD
CONTACT SPRING
LOUNCHING TUBE
ELECTRIC BULB
TAIL LATCH
BREECHGUARD
TRIGGER
STOCK
SIDE VIEW
GUIDING FINS
DRIVING CHARGE
EXPLOSIVE
CONTACT WIRE
THE ROCKET PROJECTILE
© 1945 C P LENT
DRAWN BY: C. P. LENT
AUG 11 1944

Resemblance to comedian Bob Burns' musical instrument, the famous bazooka, inspired the name of this newest weapon of destruction.


ABOUT FIVE (5) FEET LONG
SIGHT
CHEEK GUARD
CONTACT SPRING
78 U.S. CALI
INSIDE DIAMETER
@ 3"
@ 6 1/2"
ELECTRIC BULB
TRIGGER
BATTERY
@ 8"
TAIL LATCH
@ 21"
@ 18"
@ 21"
BATTERY
WIRING DIAGRAM
CONTACT SPRING
ROCKET PROJECTILE
CONTACT WIRE
TRIGGER
BATTERY
GROUNDED
ELECTRIC BULB
THE BAZOOKA
ROCKET LOUNCHER
ASSEMBLY - DETAILS - WIRING DIAGRAM
DRAWN BY: CONSTANTIN PAUL LENT
DATE: AUG 1? 44
REMARKS:
SCALE: NO SCALE
DIMENSIONS: APPROX.
DRAWING № 3706.
© 1945 C.P. LENT.

The propelling charge lets go with a terrific blast from the rear of the bazooka. The projectile leaves the tube at high sped driven by the jet of gas which is produced by the propelling charge. This is the force that drives the rocket to its destination. The firer experiences no after effects as there is absolutely no recoil. It is understood that the loader must always keep away from the open rear of the bazooka.

The bazooka has been proclaimed revolutionary and the most effective new weapon in this war. It has been said that in the first days of the invasion of Sicily, a few bazooka-armed soldiers destroyed more than half a dozen German tanks of the heaviest make with a few minutes.

In the drawings presented in the following pages, there is shown a complete design of a bazooka rocket gun including several details and a wiring diagram. One can see at a glance that the whole thing is so simple that it can be built by a mere child. It is said that a bazooka can be manufactured at a cost of only $8.00 for the complete unit.

Pyrotechnic Piledriver — This slender handful of destruction has become a great favorite with American troops in action against the enemy.

EARLY RESEARCH

In the last chapter a general definition and history of the rocket has been given including a broad history of research done by a number of early experimenters who practically starting from nothing developed a science which now seems to offer uncalculated opportunities and which has a chance of developing into one of the largest transportation organizations the world has ever known.

Although at the present time rocketry is a science the engineering profession does not have to be ashamed of, one of the questions, among many others that was most often asked in the past was, "How does a rocket motor exert force?" A companion question is, "How can a rocket work in a vacuum where there is nothing for it to push against?"

Both of these questions can be answered graphically with the aid of this simple representation of a rocket motor, or combustion chamber. (See Fig. 37).

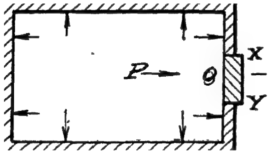


FIG. 37

Assume a chamber ABCD, walled solidly on all sides. An explosion takes place within it, building up pressure, P. According to our knowledge of the behavior of gases under pressure, the gas confined in the chamber will push equally on all sides, but the chamber will not move, for a push in any chosen direction will be exactly counterbalanced by a push in the opposite direction.

Now, assume that the partition xy is removed, allowing the compressed gas to escape through the orifice O. Under these circumstances there will be a push against the wall AB which is not fully counterbalanced by a push on CD. The chamber will tend to move in the direction of AB, with a force equal to the pressure on AB, less the pressure on what remains of the wall CD.

This explanation and the one presented on Page 5 and Fig. 4 makes apparent the mechanism by which reaction is transmuted into motion in the rocket motor. It also shows why such a motor would work as well in a vacuum as in air, if not better.

We have seen that the lift of our theoretical motor is equal to the pressure on the wall AB, less the pressure on what remains of the wall CD. The push on the latter, obviously, will be equal to the original pressure on it, less the pressure on the area of the opening xy.

The lift of the rocket motor, therefore, will be equal to the pressure inside the chamber, multiplied by the area of the nozzle opening, plus or minus gains or losses due to expansion of friction in the nozzle flare. If the nozzle opening is circular, the formula for lift become:

$$L = P\,(\pi R^2) \pm x$$

Where L is the lift, P the pressure in the chamber, m^2 the familiar formula for circular area, and x the gain or loss resulting from the passage of gas through the nozzle. In ordinary calculation the value of x may be ignored, though a combustion chamber might be so badly or so excellently designed that the values of minus or plus would become an important part of the total.

It follows from the formula that very little change in the diameter of the nozzle will make a great difference in the lift of a given motor, provided the pressure in the chamber remains constant. Conversely, the lift may be considerably varied in the same motor, with constant nozzle diameter, by varying the pressure, as shown in the following table, in which the value of x is ignored:

Nozzle in inches Diameter	Combustion Chamber Pressures (in lbs. per sq. inch) Lift Pounds			
¼	7.4	11.0	14.7	73.5
½	29.5	44.2	58.9	294.5
¾	66.3	99.5	132.5	662.7
1	117.8	176.6	235.6	1178.1

From our illustration it is clear that the chief factors, as far as the lift is concerned, are pressure, the cross-section area of the nozzle and the shape of the nozzle. The size and shape of the combustion chamber does not enter into the calculation.

Size and shape are of paramount importance, however, in determining the **efficiency** of a rocket motor. Following propositions seem to be of fundamental importance:

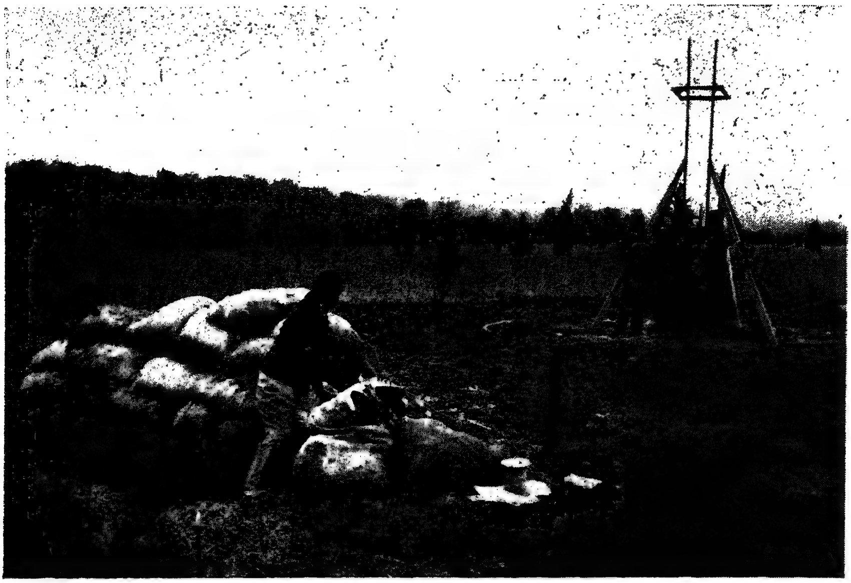


FIG. 38

A photograph by the American Rocket Society showing the terrain of land suitable for rocket experimenting. Some of the members of the society are shown huddled around the launching rack while another in hiding in the rear of piled sandbags.

1. The chamber should be as small as possible commensurate with the quantities of fuels and gases handled.

2. The interior should be so designed as to facilitate the movement of gases and unburned fuels.

3. The routing of fuels and flame should be such as to assure complete combustion before the gases leave the nozzle.

Unlike the items earlier discustsed, the problem of motor design does not lend itself readily to mathematical treatment. Experimenters have had most success with chambers which contain no pockets or corners. The favored shape is that of an elongated sphere, or that of an egg, with the small end opposite the nozzle.

The diameter of experimental motors is usually three to four times that of the nozzle. As to the size of combustion chambers, efficient motors have been constructed with lengths varying from 1½ to 3 times their diameter. Most experimenters favor introducing the fuels through inlets in the base of the motor, near the nozzle, the fuels being directed upwards along the walls. This method appears to facilitate the movement of the gases, and to promote good combustion. (See Fig. 52, page 47.

The inside dimensions of a small but successful motor tested some time ago were as follows:

Chamber diameter	1½ inches
Chamber length	3 inches
Nozzle length	3 inches
Nozzle opening (small end)	½ inch
Nozzle opening (large end)	¾ inch
Oxygen fuel inlet	⅛ inch
Gasoline fuel inlet	1/16 inch

It is evident that a rocket motor will be unable to extract all of the energy from the gases as they leave the chamber, except in the case where the speed of the motor is equal to or greater than that of the gas. In all other cases the products of combustion will leave the chamber bearing with them considerable amounts of unrecovered energy.

One of the most practical ways for recovering part of this power is the flared nozzle. The theory is that as the gases leave the chamber they will expand, exerting lateral pressure on the side walls of the nozzle. On the principle of the inclined plane, this lateral pressure can be turned into forward pressure when the nozzle is properly designed.

The flare is thus in the nature of a refinement on the rocket motor. For rockets moving at slow speeds the amount of energy theoretically recoverable by this device is an important fraction of the whole. It is obvious, however, that an

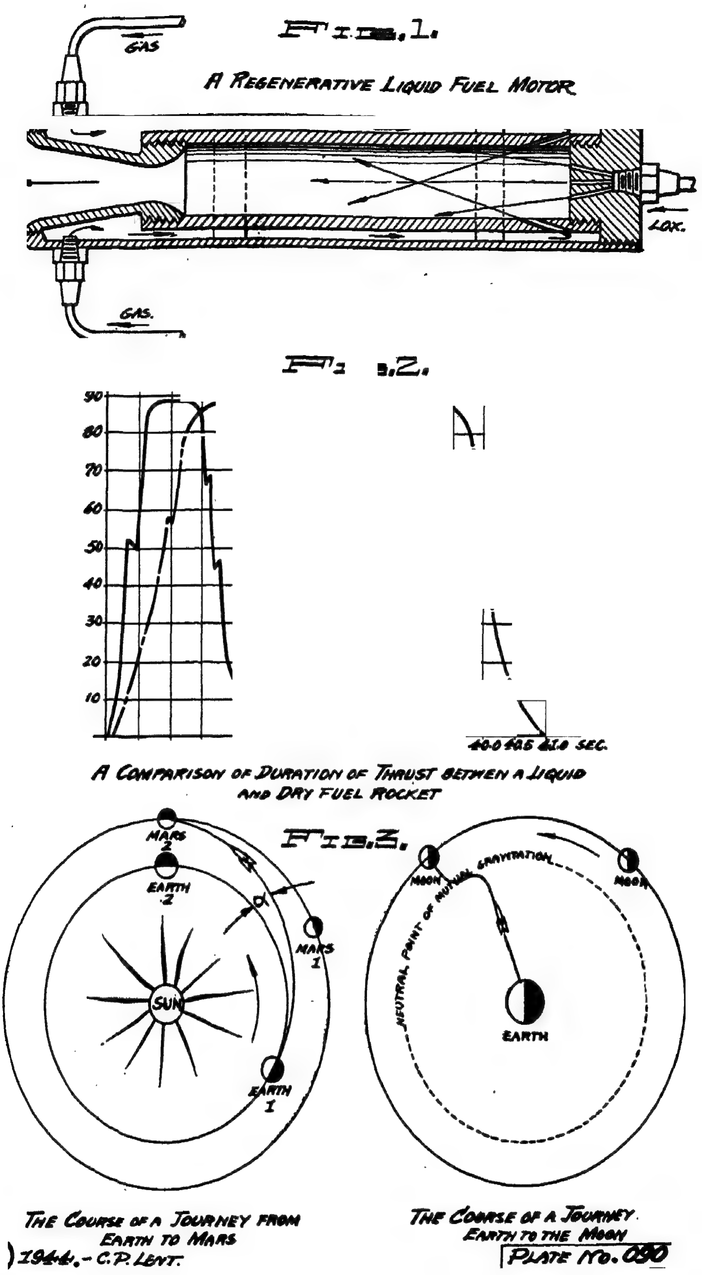


Fig. 1.
A Regenerative Liquid Fuel Motor
GAS
LOX.
GAS.
Fig. 2.
90
80
70
60
50
40
30
20
10
40.0 40.5 41.0 SEC.
A Comparison of Duration of Thrust between a Liquid and Dry Fuel Rocket
Fig. 3.
MARS 2
EARTH 2
MARS 1
SUN
EARTH 1
MOON
MOON
NEUTRAL POINT OF MUTUAL GRAVITATION
EARTH
The Course of a Journey from Earth to Mars
1944. - C.P. Lent.
The Course of a Journey Earth to the Moon
Plate No. 090

FIG. 39

On the top is a cross-section through a Regenerative Liquid Fuel Motor. The fuel is injected on the nozzle end and travels the full length of the motor entering the combustion chamber in the forward end where it is mixed with liquid oxygen. While the fuel travels along the lining of the motor it absorbs excessive heat thus preventing the burning out of the nozzle. Fig. 2 illustrates a comparison of duration of thrust between a liquid and a dry fuel motor. The dotted lines is the reaction for the liquid fuel while the straight line for the dry fuel rocket. In Fig. 3 it is illustrated the manner in which a space ship might be made to reach from the Earth to the planet Mars—or from the Earth to the Moon. Note relative positions of the Earth to planet Mars and the Moon prior to launching the ship.

elongated nozzle, with or without flare, will tend to retard the lift of the motor, due to friction. The actual amount of energy recovered, then, will depend upon the excess of expansion "push" over the friction necessarily developed. It follows that the angle of flare will vary for every fuel used, and also for every different pressure developed in the chamber. Likewise it is clear that a slightly bell-shaped flare will be more efficient in all cases than a straight-angle enlargement.

The higher the pressure developed in the chamber, the faster the gas will be moving upon ejection, and the narrower the flare will have to be to gain energy by expansion. Also, the nozzle should be longer, for high pressures than for low. Through fine calculation it was possible to determine the point at which diminishing returns accompany further elongation, due to greater friction and greater weight.

The pressure developed in any rocket motor depends upon the speed with which the fuels are fed, the completeness of combustion, the ease with which the gas under pressure can escape through the nozzle, and the nature and specific behavior of the fuels.

Assuming that the combustion of the fuels is complete and practically instantaneous, we must consider two cases: (1) in which the fuels are fed by a positive pressure pump, and (2) in which the fuels are forced into the chamber by gas pressure in their tanks.

When the fuel is **pumped** into the chamber, the pressure depends upon the volume of gas generated by the combustion of the fuel per unit of time, and the volume able to escape through the nozzle in the same unit of time. The pressure in a given system varies with each fuel used. The pressure in the motor can be changed in three methods: (1) increasing the speed of the pump, (2) using a fuel of greater energy content, and (3) altering the area of the nozzle.

The comparative simplicity of rockets in which the fuels are sent into the combustion chamber by gas pressure in the tanks makes the problem of pressure in such motors especially interesting. Moreover, in such a case, the approximate calculation of the pressure is greatly simplified.

In such a system the fuels flow at a rate dependent upon the difference between the pressure in the fuel tanks and that encountered in the combustion chamber. Since the pressure existing in the combustion chamber counteracts that in the fuel tank, when these two forces are exactly equal there will be no flow of fuel at all.

In a rocket motor the pressure in the chamber is created by combustion of the inflowing fuels, part of the pressure simultaneously escaping through the nozzle. Therefore, when combustion begins, the pressure will mount rapidly in the chamber to a point just short of the tank pressure, less line friction and other losses. For practical purposes, it may be assumed that the pressure in the chamber will then maintain an equilibrium with the forces behind the fuels at their entry ports, of such a nature that continuous flow will take place in just sufficient volume to offset the loss of pressure through the nozzle.

Thus, the pressure in a given chamber, provided the fuel entry ports are the proper size to permit inflow with sufficient rapidity, will approximately equal the pressure behind the fuels in the tanks. Obviously it cannot be greatly less, else extra fuel will spurt in to build up the pressure. It cannot be more, or the flow will stop.

The only exception to the latter observation is in the case of an "aspiring effect" developing in the motor. Some experimenters claim to have observed such an effect, which they ascribe to the rapid circulation of streams of gas past the entry ports, setting up areas of pressure lower than that generally obtaining in the chamber, and thus permitting fuels to enter at lower pressure than would otherwise be the case. The possibility of aspirating effect is not to be denied, and combustion chambers must be devised which will such in their fuels with little or no outside assistance, just as steam boilers can be made to feed themselves with cold water without recourse to pumps. This is a field that requires considerable research and experimentation, however, before the practical builder of rockets can take advantage of it.

If the pressure that actually develops in an experimental motor is conspicuously less than the pressure in the fuel tanks, faulty design is indicated. Faults may be looked for at five points: (1) the nozzle may be too large for the capacity of the chamber, (2) the fuel entry ports may be too small, (3) there may be clogging or excessive friction in the feed lines, (4) the proportion of combustible fuel to oxygen may be wrong, or the fuel poor in quality, and (5) the chamber may be so badly designed that combustion is intermittent, irregular or incomplete.

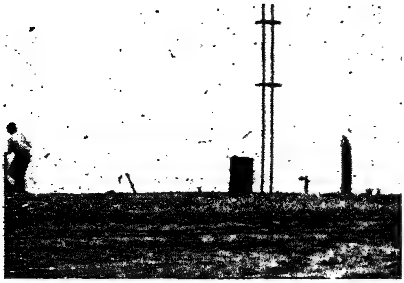


FIG. 40

Flight of an experimental rocket built by the A.R.S. The rocket has just cleared the launching rack and is traveling in a straight trajectory. The disadvantage of a twin cylinder rocket is the fact that any slight difference in weight between the fuel within each cylinder will throw the rocket off balance and curve its trajectory.

The following calculations depend primarily upon the lift of the motor; the weight of the rocket and the fuel, and the resistance of the air.

The acceleration of a rocket may be obtained with this formula:

$$A/g \qquad \frac{W}{W}$$

where A is acceleration, g the acceleration of gravity, L the lift of the motor in pounds, and W the weight of the loaded rocket in pounds. By this formula, if a rocket weighs ten pounds, and its motor lifts thirty pounds, the acceleration will be 2g, or twice the acceleration of gravity.

This figure must be later refined by making a double calculation, applying the formula first to the weight of the rocket loaded with fuel, then to the rocket empty. Averaging the two acceleration figures gives the average acceleration of the rocket throughout its powered flight, air resistance being left out of account.

The height to which a rocket would shoot in a vacuum may be calculated thus:

$$\frac{1}{2}\ At^2$$

where A is the acceleration in feet per second and the time in seconds. This figure must be doubled to find the full height to which the rocket would fly, since in a vacuum the upward distance covered on momentum would be exactly equal to that traveled during powered flight.

Let us not assume, however, that a rocket will fly anything like as high in air as this calculation indicates. The resistance of the atmosphere is very great, at least within twenty to fifty miles of the surface of the earth. Moreover, it increases roughly as the cube of the speed; the faster the rocket is capable of traveling the greater the resistance it will encounter. For an interesting shot of a liquid propelled rocket at the instant it was leaving the launching rock. (See Fig. 40).

Even with a rocket of the best possible streamlined design, the calculation based upon flight in a vacuum should be divided by three or four. If the figures show that your rocket should make an altitude of twenty miles, air resistance not taken into account, you may be fairly safe in expecting an actual altitude of four or five miles, providing the flight is perfectly straight and approximately perpendicular to the earth's surface, and the rocket well streamlined.

This particular chapter relating to early research is as its name implies only advancing fundamental data pertaining to rocket design, and other calculation. The early experimentalist and scientist in rocket development had very little to go by. Since then more complex and better formulas had been devised, some will be given later on.

The reader, to understand the secrets of Rocketry, simple as they are, should first digest this impromptu information on early research as it has been related in these few lines.

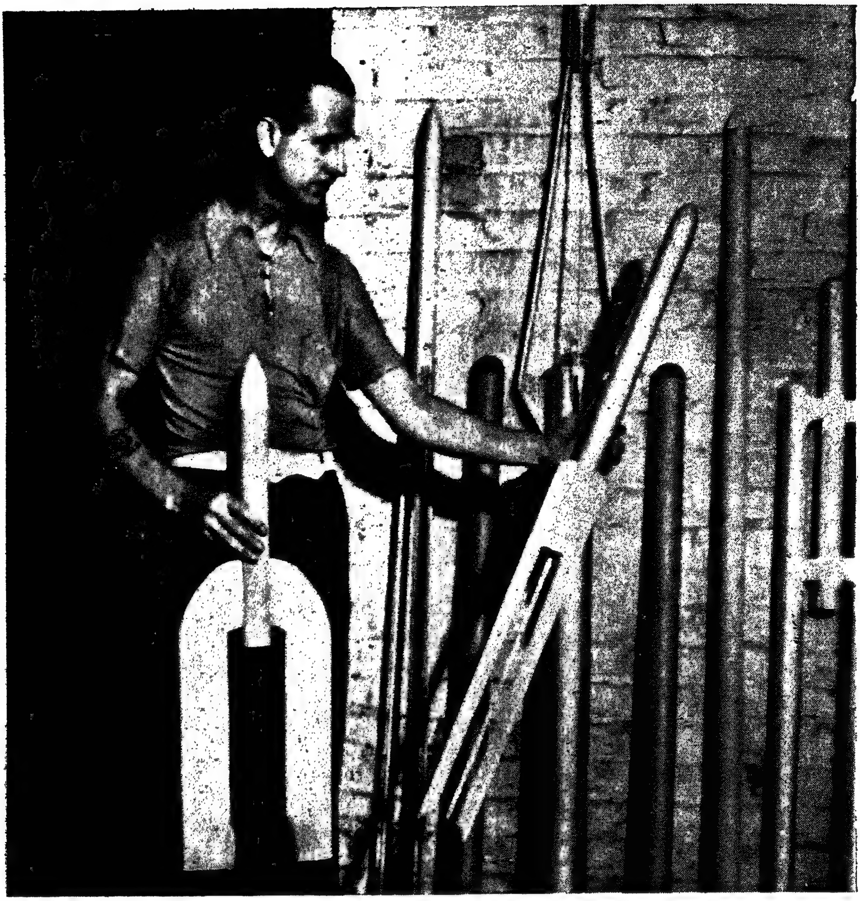


FIG. 41

To ascertain the stability of various rocket designs many such models as shown above have been tested by the members of the American Rocket Society. The rockets are in this case gun-powder rockets and their shells are made of paper and wood.

THE AMERICAN ROCKET SOCIETY

Here is a "dream that has come true". When the American Rocket Society, (Interplanetary Society it was called then) was organized around 1930, its founders—G. Edward Pendray, David Lasser, Nathan Schachner, C. P. Mason and a few others—were called visionaries and impractical men by those who always know "what and how" For many years the Society struggled along being financed in its experimental work by the dues of its members and what the experimenters could spare from their own earnings. At the beginning imagination ran high and all that was talked about was the possibility of interstellar travel by means of rockets which are the only device that can fly in the vacuum. (I wish to mention here again that rockets do not fly because the exhaust gasses push against the surrounding air, as some very well informed indiviuals still believe, but solely by the reaction principle expounded in page 27). But as the years progressed it became apparent that much was to be done as yet until this could be accomplished. In between, hands and heads have not been idle and a lot of work was done in experimentation and in the development of various rocket designs, motors and especially of formulas and charts for rocket calculations. The A.R.S. was the first to work out and publish in its quarterly magazine "Astronautics" actual field tests of rocket performances and formulas for rocket calculations. Certainly, Pritain and Germany did a lot of work on rockets, but upon the entry of this country in the war the only real information available here were the issues of this quarterly publication and some records of the work done by the eminent scientist Dr. Goddard. The result is that, while for many years before the war the members of the Society had to struggle along on shoe strings, now they are in great demand not only by the industry but also by the government alike. The members of the A.R.S. are the very few that know anything about rockets. The Society is now a great success and its membership is around 400 members. If there is anyone that is going to be very busy right after the war it will be these visionaries and impractical men—and rocketry will be the biggest thing in modern transportation history.

RESUME OF EARLY EXPERIMENTS BY THE AMERICAN ROCKET SOCIETY

In this chapter excerpts from reports on early rocket flights are submitted to the scrutiny of the reader to illustrate to him the difficulties which had to be overcome by early experimenters before simpler and more successful motors could be developed for better performance. If some misrepresentations of data should be encountered the reader should note that at that time no better answers could have been given until further experiments showed the fallacies of former theories. With this in mind, following are reports of the year 1932 of the performance of experimental rockets built by the American Rocket Society and propelled by liquid oxygen and gasoline.

The first experimental rocket that was tried out was a rocket that reached firing a trifle more than 2 seconds, but at that height the flight was brought to an abrupt end by the bursting of the oxygen tank.

Despite this mishap, the experiment was considered a success. It proved without doubt the efficacy of the rocket motor developed by the Society, and gave the first actual experience with the firing of a liquid fuel rocket. The accident proved the need of redesigning future rockets with a view to placing the oxygen tank well beyond the reach of the flame.

This rocket was not a completely new rocket. Many of its parts, including the tanks and motor, were salvaged from another rocket built by the Society, which performed successfully on the proving stand used to test motors before Actual flight.

The earlier rocket consisted essentially of two cylindrical aluminum alloy tanks, each five feet long and 1½ inches in diameter. These tanks carried the rocket fuels. They were fastened together at the upper end by tie-pieces, upon which the combustion chamber was held in such a way that the flame from the nozzle jetted down between the tanks. The distance betwen the fuel tanks in the old rocket was eight inches.

Due to a desire for lightness, the metal which held them in position was not very strong, with the result that the shocks and jars of transporting the rocket to the experimental site was sufficient to move the motor, tanks and fins out of proper alignment. Moreover, the original rocket was surmounted at the top by a split, pointed hood designed to hold the parachute. Due to the non-rigid construction, it was almost impossible to make this apparatus fit properly.

In constructing the rocket now tested, the Society set out to overcome as many of these difficulties as possible. Taking the old tanks, removing the tie-pieces which originally carried the motor, and fastened this member between the upper ends with clamps and bands, the result was an exceedingly simple assembly, considerably more compact and rigid than the former arrangement. (See Fig. 20).

The lack of structural strength exhibited by the earlier rocket was one of the problems which finally led to a decision against launching it. In the new rocket the motor and tanks were so firmly held together that it was unnecessary to fasten the tanks together at the lower end. The only device needed there was a band to carry the guiding fins.

Another step toward simplicity of construction was the adoption of the air cooling doing away with the awkward and heavy water jacket around the motor. Movements of air past the motor was made possible by designing the motor case of thin metal, and leaving a hole in the top, through which air could rush during flight.

Since the original motor (which had been designed for water cooling) was being used, there was some doubt about the efficacy of this step. It was not practical to weld cooling fins to the motor, but it was assumed that it would not get too hot. Earlier experience had shown that 20 seconds of firing had failed to warm the cooling water enough to boil it.

The same valves were used as in the original rocket, but the springs were dispensed with. By a simple device both valves were turned on simultaneously by pulling a cord. This eliminated the uncertainty of the electrical firing method used at first but developed some new difficulties of a special kind which had to be considered in planning the next rocket.

One other innovation of the new rocket was—the guiding fins. Those were made of balsa wood, which, because of its lightness, seemed especially suited for this use. Thin metal fins, such as were

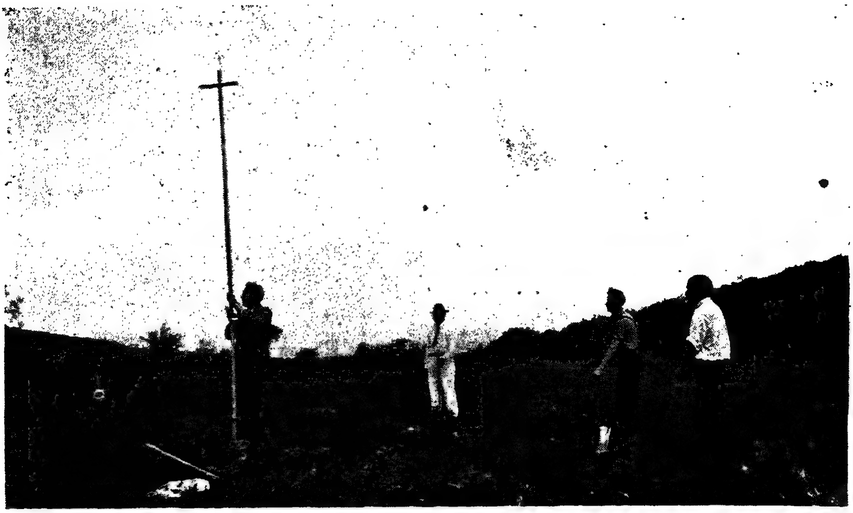


FIG. 42

View of the field at Pawling, N. Y., where flight stabilization tests were made. Note in the photograph the absence of houses and the size of field. One of the members of the society is shown raising the launching rack while others are securing the supporting cables.

used on the earlier rocket, lacked rigidity and this difficulty could not easily be overcome without adding to the weight. The balsa wood was inexpensive, easily worked, and was coated with metallic paint for appearance and at least partial resistance to fire.

The inability of this material to withstand direct exposure to the rocket flame was borne out by the test, and was not used in any successive rocket designs.

The rocket now tested was fired at Marine Park, Great Kills, Staten Island. The launching rack was designed and constructed at Great Kills, and later transported to the site of the experiment in sections. The rack consisted of two 2-inch pine poles each 15 feet in length, fastened together at the base by a four-by-four timber and other under-structure, and at the upper end and middle by wooden shackles so arranged as to give the fins of the rocket clearance during passage. On location, the base of the rack was buried about two feet in the sand, and held in place by six guy ropes. The rocket could be inserted by springing the guide poles apare at the lower end. Before the flight, the poles were soaped to reduce the friction of passage. A piece of sheet iron was fitted between the poles as a platform for the rocket.

The launching rack was inclined to about five degrees out to sea, the intention being to direct the flight definitely away from land. It had previously been learned, by calculation and actual test, that the rocket would float until recovered. To aid discovery in the water, the ends of the fins had been painted a bright red. For a photograph of the performance of this rocket see Fig. 40.

Twenty-five feet to the left of the rack the valveman's dugout was constructed, large enough to shelter three men—the lighter, his helper, and the valveman. Seventy feet to the rear of the rack a larger dugout, capable of holding about fifteen persons was constructed. Here were stationed the command, the timer and other observers. Another observation post was established 1,000 feet to the right of the rack, where a transit was set up to aid in calculating the hight of the flight.

Other equipment needed for the experiment included a tank of nitrogen gas under pressure, and fifteen litres of liquid oxygen—and gasoline. The latter was a special mixture containing a small percentage of tetraethyl lead, prepared expressly for this test.

The rocket, launching rack and other materials were ferried to the site of the experiment in small boats. The preliminary construction work was done early in the morning, and by a little after nine o'clock the apparatus was ready for a ground test, considered necessary in order to make sure that the rocket was in proper working order.

At ten o'clock, everything having been found in order, the rocket was charged with one pint of gasoline, and clamped firmly in the launching rack. For this test the balsa wood fins were removed.

When pressure was applied to the gasoline, it was discovered that a slight leak had developed in one of the valves. Before the pressure could be relieved, the valve was accidentally opened for a moment, and some of the gasoline escaped, leaving probably about half a pint for the test. In view of the lateness of the hour, it was decided to proceed with the test despite the leak, and to put pressure on only after the oxygen had been loaded into the rocket.

The oxygen was poured in through a specially made funnel. With this apparatus the oxygen filled in rapidly, and there was no such delay and discomfort as that experienced in other tests. Two litres of oxygen were poured into the tank, approximately half of this evaporating during the pouring.

When the oxygen valve had been screwed down, the timer began to call time in ahlf-minutes as another member put in the nitrogen for pressure. This done the motor-case was set in place. The valve-key was inserted and the detachable lever which opened the tanks attached. Then the valveman took his place in the duggout

At three minutes the wick was ignited below the motor, and soon after the valves have been opened.

The rocket performed well in the test, though the flame was, at first, unsteady and of a yellowish color. Toward the end of the test the color improved, possibly with the heating of the fuels, or it may have been that changing pressures in the fuel tanks brought about a better mixture.

The rocket fired only eight seconds in the test, the short period probably being due to the small supply of gasoline. Since the lift of this motor had been measured earlier, no lift-measuring apparatus was used in the test.

Examination showed that the firing had heated the motor considerably. It was too hot to touch, and sputtered when warm water was thrown against it. The force of the flame had torn a protecting layer of asbestos from the inner parts of the fuel tanks, and had thrown sand for fifteen or twenty feet from the base of the launching rack.

The test having proved satisfactory, the fins were fastened in place on the rocket, and it was refueled as rapidly as possible.

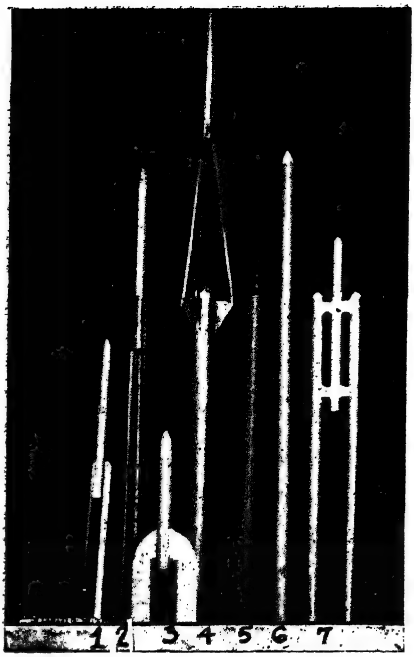


FIG. 43

A number of test models used in stabilization test. Note the various designs and sizes.

About a pint and a half of gasoline was put into the tank, and two litres of oxygen, of which a little more than one litre remained at the end of the loading.

The gallery of observers had been augmented by members of the Society, representatives of the Bureau of Combustibles of the New York Fire Department, and curiosity-seekers who had been attracted by the earlier activities on the island. Members of the Society were posted to warn small boats away from the side of the island toward which the rocket was aimed. Others helped to keep spectators at a safe distance. Two cameramen, one representing Acme News Pictures, and the other Universal Newsreel, had taken preliminary views, and then taken a position about 800 feet to the rear left to photograph the flight.

A stiff offshore breeze had sprung up and though this interfered slightly with the pouring of the oxygen, it was considered advantageous in tat it was believed that the breeze would tend to blow the rocket away from shore, thus cooperating with the tilt of the launching rack in guiding the rocket out to sea.

The duties in connection with operating the rocket were performed by the same

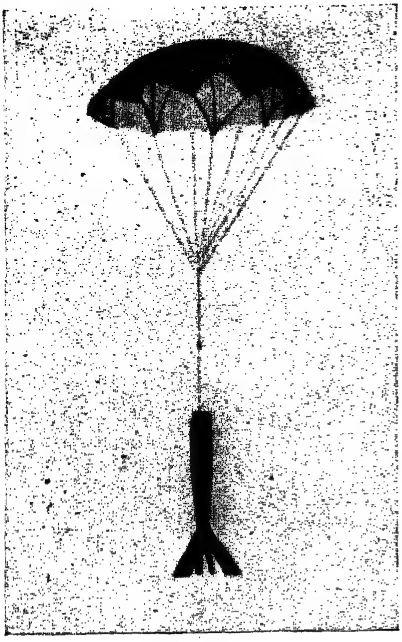


FIG. 44

A photograph showing a rocket descending by means of a parachute.

men and in the same manner as during the ground test. The torch was applied a few seconds past the third minute. Everything seemed to be going off well until it was attempted to pull the cord which opened the rocket's valves. At this point, the detachable lever, probably loosened by the wind, fell off the rocket. Then one of the members of the Society courageously ran up to the rocket, where the fuse was burning merrily close to an oxygen tank that must by that time have been under pressure of nearly 300 pounds, and replaced the lever.

In this excitement, or perhaps because of necessity, the valves had been opened before our hero had regained the shelter of his dugout. The photographs show that he was fully exposed at the time the rocket started. Fortunately there was no explosion at that point, and he was unharmed. (See Fig. 40).

The rocket roared upward almost instantly, with a sound not unlike that of a large sky-rocket. As soon at is was clear of the launching rack, instead of heading out to sea, it began to veer into the wind, taking a course at right angles to that intended. It seemed likely that this was due to the effect of the wind on the fins, blowing them out and thus causing the apparatus to steer into the breeze. It may also have been aided by the accidental striking of the fins upon the upper part of the launching rack. Such striking did occur, as subsequent examination showed.

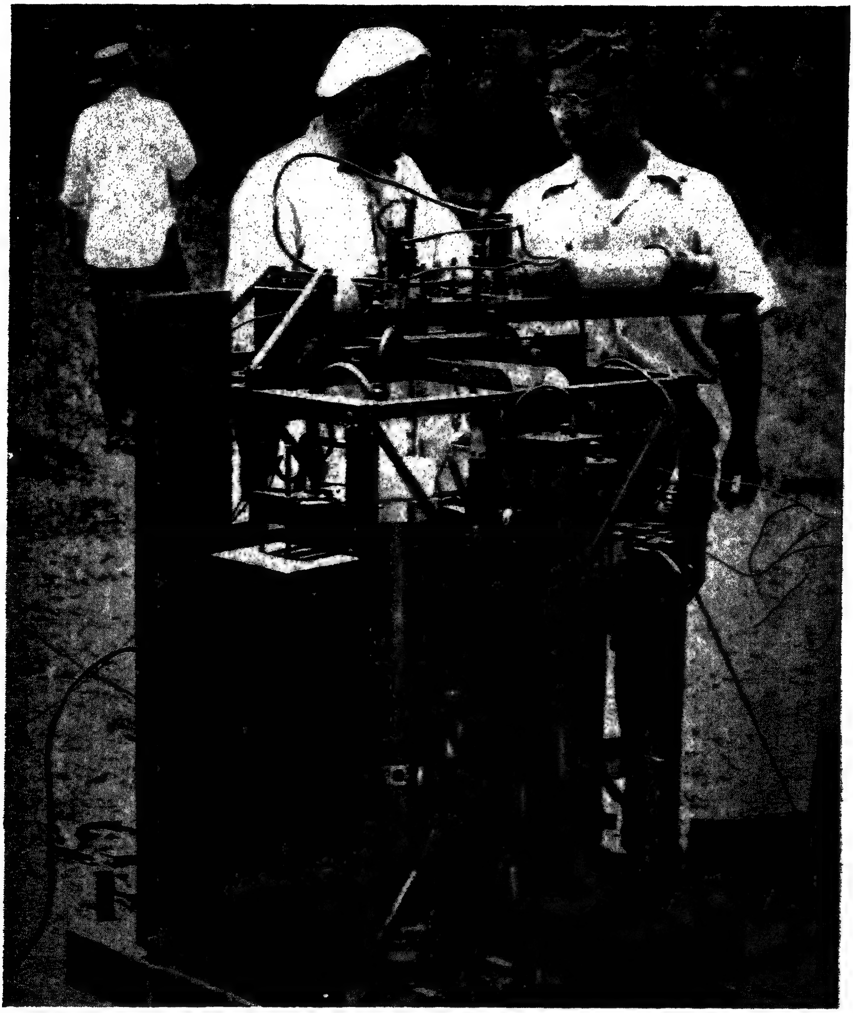
During the flight, however, observers had little time to notice details. The rocket gathered speed rapidly, despite the shortness of the flight, reaching an estimated velocity of about 200 feet per second, at an altitude of about 250 feet. At that point the oxygen tank exploded with a loud pop.

The apparatus was almost instantly covered with the yellowship flame of burning gasoline. The guiding fins were thrown off. The tanks and motor continued the flight for several hundred feet, but fell over parallel with the ground. They finally dropped into the water about 400 feet offshore, and were retrieved by two boys in a small boat. The fins dropped nearer to the land, and were rescued by a member by wading out into the water.

Hasty examination showed that the oxygen tank had ripped open near the middle, along a vertical line on the inside where it had been most exposed to the flame. The ripping was not due to the melting of the metal, but to a disrupting force from within, possibly aided by the softening effect of heat at that point where the bursting occurred. The fundamental cause, obviously, was the pressure rapidly built up in the oxygen tank by the extreme heat of the motor flame. This pressure was greater than the safety valve could relieve. The nozzle of the motor appeared scored and pitted, but it was not possible to tell how hot it had been. When brought out of the water it was cool.

After this mishap another rocket was tested sometime later. In this particular design, the fuel tanks were arranged concentrically, one about the other, around the rocket's motor; that it, built up from a series of duralumin tubes of increasing diameters. The gasoline container was innermost, encircling the motor. Next was the nitrogen tank, and outside of all the oxygen tank, each attached to the others by welding wherever possible. The outer tank wall of each tank constituted the inner wall of the next tank.

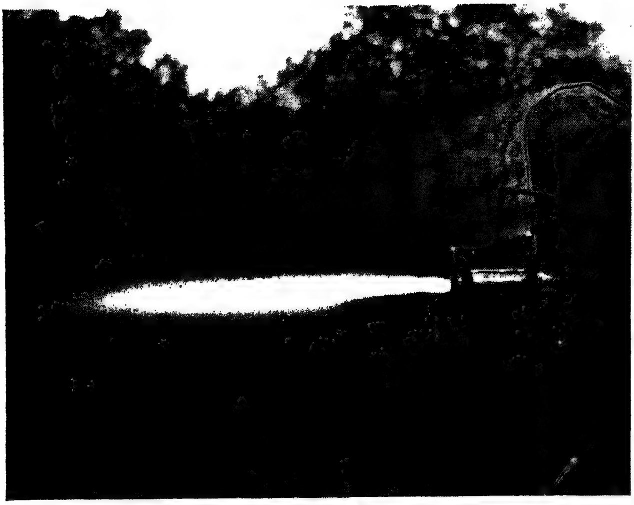
The motor casting, of special aluminum alloy, consisted of an egg-shaped blast chamber leading into a conical expansion nozzle. The blast chamber projected above the tanks and was surmounted by a removable cap held on with bolts. This arrangement permitted easy inspection of the chamber and nozzle throat.



HECHT

Above an early experimental test stand of the American Rocket Society.

In the photograph one can see the intricate arrangement of fuel tanks, valves piping The testing of rocket motors is a "must" in rocket research and it is much more important than the firing of a rocket. When a rocket is in the air, very little can be conjectured of the performance of the motor. But upon the test stand, the pressure within the chamber, the temperature and the thrust can be measured exactly, and in addition, the general behavior of the motor can be analyzed.



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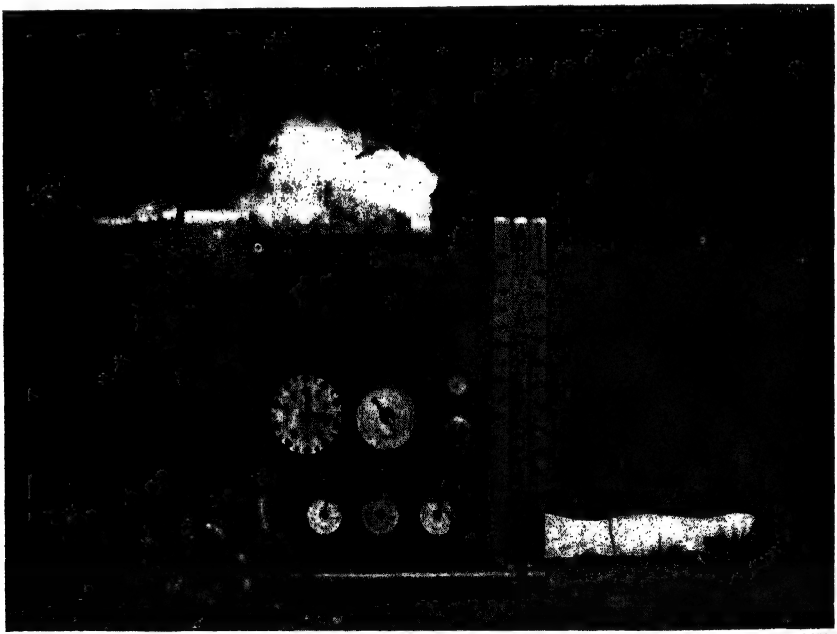
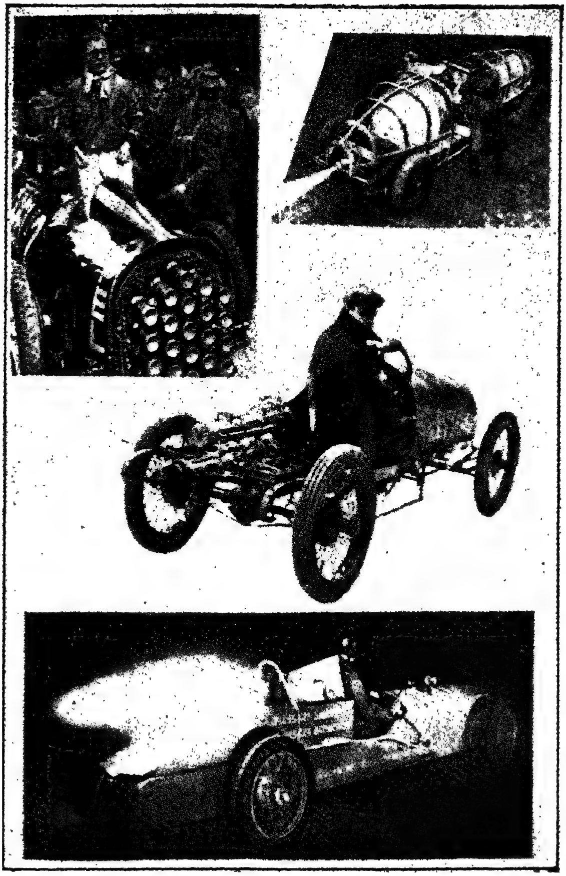
Motor in Action—Underexpansion is visible in form of jet near nozzle. Note moisture in air condensing as it is sucked past the oxygen line.



HECHT

The various dials upon the test panel are used to record the results of the test while a photographer takes pictures of the dial registrations during the test and another one takes color pictures of the jet of the motor. From these pictures, later on, charts are prepared and formulas are drawn up. Should a motor behave favorably on test, it can be used successfully in an actual rocket shot with the assurance that it will propel the missile to its destination. An advice to experimenters is therefore: build your test stand first; second, build your motor; third, test your motor; fourth, build the rocket body proper; fifth, test the body aerodynamically; and then, if motor and body tests are favorable—make sure your parachute release works properly, then shoot your rocket, and keep your fingers crossed.



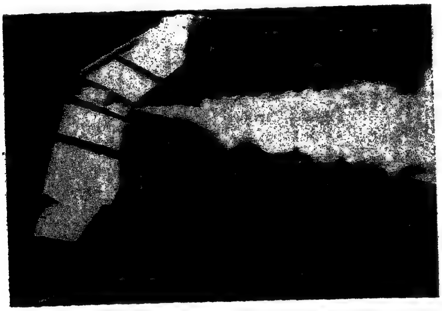
II

With all the progress that has been made in recent years with rockets, rocketry is still in its infancy. Although gun-powder rockets are old, the liquid propelled rocket in an invention of the 20th century. While not much progress has been made with dry fuel rockets through the years, tests with liquid propelled rockets advanced rapidly. In the above photographs are shown some more interesting examples of early dry and liquid fuel rockets. The picture in the upper left is showing a rocket vehicle of Fritz Van Opel with its inventor. Van Opel was a large manufacturer of medium priced automobiles in prewar Germany, similar to Henry Ford in America. He was ambitious and dreamed of perfecting a rocket propelled craft. He was not successful with his idea and all he has gotten out of it was some publicity and a number of spectacular motion pictures and photographs. Really he was not the imaginative type. Valier, on the other hand, lower pictures, had more imagination. He was one of the first to use liquid fuel motors of which these are actual photos of automobiles using his motor. Both Van Opel and Valier got killed while testing their inventions—the first martyrs in rocketry. Another martyr is Tilling, who got killed accidentally, with a number of his assistants, when charging one of his rockets with gunpowder. For pictures of the Tilling rocket, see Figs. 15, 16 and 27.

Anglo-American Thermal Jet Plane

Designer Whittle Overcame Inertia, Discouragement

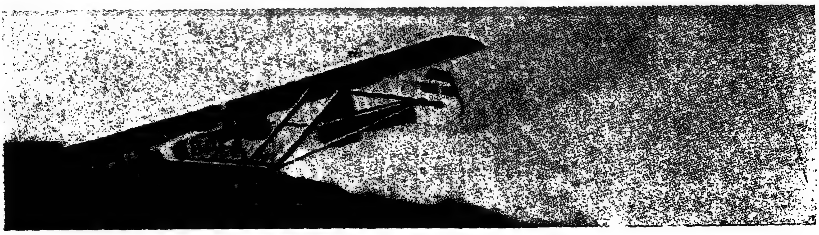
Commander Frank Whittle — Designer of first Allied thermal-jet aircraft engine.



Model Planes — Rocket propelled,

Similar to all proponants of jet propulsion, in the days before the present war, the man who is today Wing Commander F. Whittle endured years of discouragement before finally seeing his thermal jet motor recognized, adopted, developed and finally hailed as a large step forward in the science of aircraft flight. One of his original supporters, Flight Lt. W. P. Johnson, has revealed that Whittle trudged from industrialist to industrialist vainly trying to obtain backing to build and test his design.

Within three months not only had a number of these engines been built and ground tested in the United States, but Bell Aircraft Company had constructed an experimental test airplane to accommodate two of the units. The first American flight was made on October 1, 1942 by Robert M. Stanley, Bell's chief test pilot. Since that time numerous Army officers have flown the "Squirt" as the ship is named. In addition to this airplane numerous other companies, both here and in England, have constructed, or plan to construct, aircraft powered with the Whittle or similar thermal jet power plants. It need hardly be added that the German Air Force has at least two models of thermal jet fighters in an advanced stage of development.



Take-off of Opel Glider during 1929 flight.

Copper feed lines (intercepted by quick-release valves) led from the fuel tanks to the combustion chamber. Pressure to force fuels in to the chamber was supplied, in the case of gasoline, from the nitrogen gas tank, and in that of oxygen, by its own vapor pressure.

The object in constructing a rocket along these lines was:

First, to keep the oxygen container away from the rocket's flame.

Second, to test the possibility of cooling the motor with one of the fuels (gasoline being in direct contact with the motor).

Third, to have the blast chamber and throat available for inspection after each firing.

Fourth, to see how much the use of a long nozzle would effect the stability and thrust of a rocket.

In the original design a venturi or thrust augmentator was provided for, but due to the weight added in strengthening certain members of the rocket, this feature was abandoned and a simple circular fin, for stabilization purposes, was attached to the after end of the main section.

The dimensions over all when completed were: height 4 feet; greatest diameter, 8 inches; diameter along tanks, 6½ inches.

The method of ignition decided upon was identical with the one used for rocket before described.

The new rocket was mounted in the launching rack and charged with 1¼ quarts of gasoline. Nitrogen gas to force-feed this gasoline was next pumped in to a pressure of 300 pounds per square inch.

An attempt was then made to fill the oxygen tank. Two quarts of liquid oxygen were fed through the fill hole, but most of it boiled off as soon as it struck the relatively warm inner tank. Further oxygen losses were sustained during the filling, when the outrushing oxygen gas persisted in spurting the liquid from the funnel. Another two quarts were fed. This time, because the tanks seemed to be considerably precooled, the out-rushing of gas oxygen was not so pronounced. The frost line on the tank also rose considerably higher than at the attempted first filling.

From former experiences, it was inferred that at least one quart was in the container, whereupon it was closed.

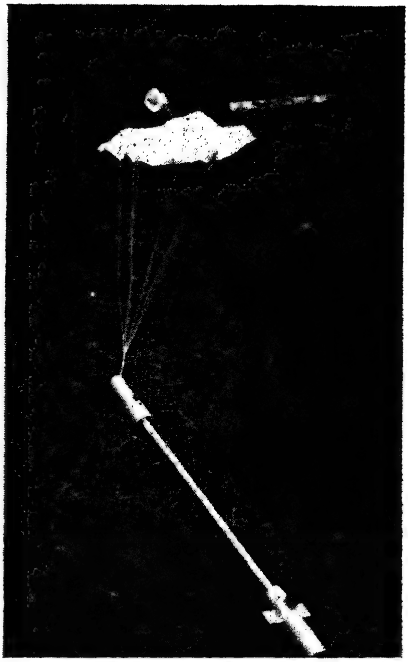


FIG. 45

The rocket and parachute arriving safe to the ground. Note the comparative size of rocket and parachute.

From the dugout, observers watched for the safety valve's release which would signify that sufficient pressure had been built up for the firing. After 1½ minutes the frost line began dropping rapidly on the oxygen tank. After another 2¼ minutes no evidence of the valving off of oxygen was apparent.

One of the experimenters then fired a chlorate and sulphur flare and another released the valves. Immediately a succession of loud "chugs" were heard as if the oxygen and gasoline were feeding intermittently. These quickly ceased and were followed by an outflow of blazing gazoline from the nozzle. As this flame, which almost enveloped the rocket, was simply gasoline burning in air and was quickly extinguished with sand.

Upon examination, no fuels were found to remain in the tanks, nor was any part of the motor scored. The inference was that only an extremely small amount of oxygen was present in the tank at the time of firing. This was confirmed in part by the preliminary "chugs" and their immediate cessation. The final conclusion therefore drawn was that this particular design would require at least twice as

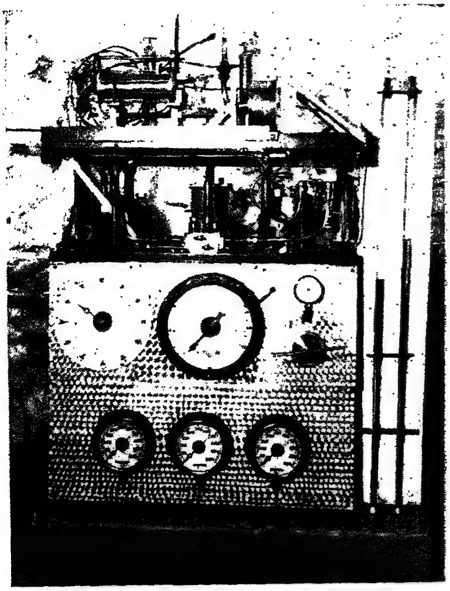


FIG. 46

The test stand of the A.R.S. which has been used for field tests on rocket motors. The stand has a plurality of gauges to record pressure, temperature and reaction of the motor. It also has a dial to record time of firing and fuel gauges to show fuel consumption.

much liquid oxygen to cool its tanks as any previous type.

As no part of the rocket appeared to be damaged preparations were made for a second test. There were only three quarts of oxygen left but, with a better method of filling, a proportionately larger quantity of oxygen was installed than on the previous attempt.

Three minutes after the tank had been closed, it was observed that the frost line was again falling. Unable to hear the safety valve release even after 4½ minutes, the observers fired the rocket. Results were identical with the previous experiment, excepting the "chugs", which were more powerful and longer sustained, indicating that a larger quantity of oxygen was present at this attempt.

All mechanical parts functioned perfectly and none showed sign of scoring or weakness during these tests.

Following this test another experimental rocket having a four-nozzle single motor rocket with tandem fuel tanks was shot. It was one of the most successful and spectacular shots ever obtained with a liquid fuel rocket. (See Figs. 3 and 52).

Careful calculations, based on a special triangulation system, indicated that the rocket reached an altitude of 382 feet at the highest point in its trajectory, landed 1,338 feet from the base of the launching rack and covered a total distance of 1,585 feet. The rocket's greatest velocity was calculated to have been more than 1,000 feet per second—approximately the speed of sound, and equal to about 700 miles an hour

Allowing for errors in discounting for air resistance, always a variable factor in accelerated flight at such speeds, it seems safe to say that the rocket attained a velocity of more than 600 miles an hour. The greatest speed previously reported was that attained in 1932 by Dr. Robert H. Goddard at his proving ground in New Mexico, where flight speeds up to 500 miles an hour were obtained.

The rocket fired approximately fifteen seconds and described an excellent trajectory, going directly out to sea. After about half the flight, a weaving or "hunting" motion was observed which might have been attributable to air resistance or to the fact that one nozzle had burned out, or possibly to both causes. The length of the trajectory and the low altitude for the long base of the curve was attributed to the burning out of the nozzle, which changed the flight direction radically. This apparently occurred at an altitude of about 350 feet.

The chief new features of this rocket consisted of the four-nozzle arrangement of the single motor, the instantaneous valves, and the method by which the parachute was opened. The latter, unfortunately, had no opportunity to prove its usefulness in this test, because the rocket took such a trajectory as to preclude the opening of the 'chute. For a successful design for a parachute see Figs. 44 and 45.

The efficacy of multiple nozzles on a single motor was well demonstrated despite the fact that the motor itself had been designed as a single nozzle chamber, and had been made over into a multiple nozzle. The indications were that much better resistance to heat and much greater efficiency would be obtained in multi-nozzle rockets when the motor had been especially designed with that feature in mind.

A new shot was made at the Society's proving ground near Great Kills, Staten Island, the launching taking place from the Society's new adjustable launching rack. This new rocket had a water jacket for cooling the motor.

Triangulation stations were established shortly after sunrise. The rocket was

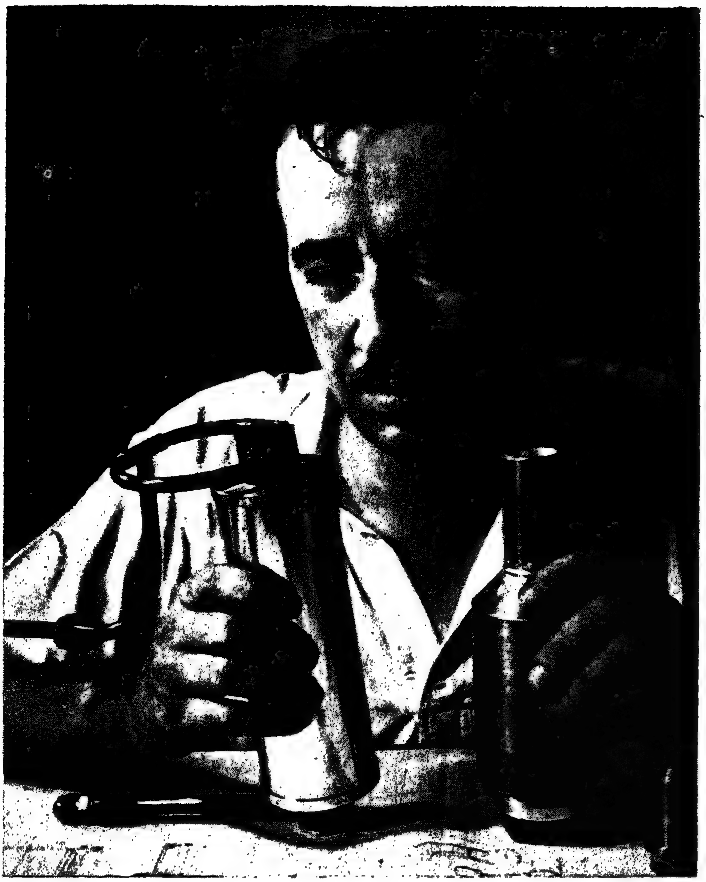


FIG. 47

Two stages of progress represented by an early uncooled motor (right) and a later model of the regenerative design. Compare the likeness of the regenerative design motor with the one shown in Fig. 14, page 10, by Valier.

placed in the rack and fueled. A quart of gasoline and 300 pounds of nitrogen pressure were put in first, followed by approximately a quart of liquid oxygen.

Five minutes were allowed to elapse before firing, in order that oxygen pressure might be built up. Directly the valves were opened the rocket leaped from the launching rack. Almost vertical flight was maintained for nearly 300 feet, at which point the rocket turned sharply out to sea. It was probably at that point that the burned-out nozzle failed and shifted the direction of the propulsion forces acting on the rocket.

The rocket rapidly sloped over until it was headed directly toward the water. Shortly after the change of direction it began to "hunt". It struck the ocean with a terrific splash, the force of the impact bending the upper part.

The behavior of the rocket during its flight as well as subsequent examination of its mechanism showed that everything had worked as planned with the following exceptions:

1. The water jacket failed to cool the motor. The heat generated by the combustion was so great that a film of steam immediately formed on the heated surfaces, thus separating the metal from the water, and preventing further heat transfer. This condition had been anticipated, of course, but it had been hoped that the presence of water would nevertheless delay the heating of the motor for the few seconds necessary for the flight. Experience showed that this hope had not been justified.

2. The firing head was faulty. The aluminum casting for the firing head was designed originally as a single-nozzle

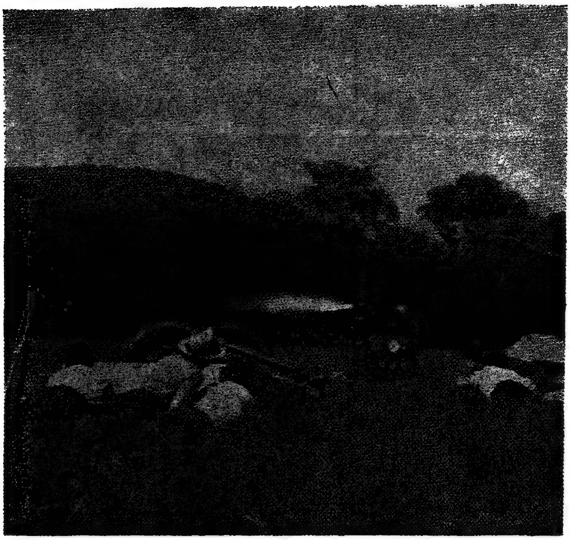


FIG. 48

A remarkable photograph showing a field test by the A.R.S. Note the jet of gases from the motor upon the test stand. To the left a camera man is taking motion pictures of the test while other members huddle the ground for safety. The roar of the motor can be heard for miles around.

motor, as used in one of the Society's early experiments. When it was converted into a multi-nozzle motor, a great deal of metal had to be cut away in the various boring and tapping operations. This left the metal wall of the casting rather thin in certain places, particularly at the points where the brass nozzles were screwed in. As there had been no way of avoiding this difficulty short of making a new casting, and since the precise nature of result was not known, the condition was allowed to remain.

At the end of about three to four seconds of firing, a hole was burned in the base of the aluminum casting, near the throat of one of the nozzles. Exhaust gases issuing from this hole and playing on both sides of the nozzle promptly melted it, blew the water out of the jacket, and so distorted the bottom plate of the latter that it got in the way of the blast from the other nozzles and deflected the stream of the exhaust to one side, making the rocket unstable in flight thereafter.

3. An examination of the interior of the firing head showed that the burning must have taken place in a fan-like sheet at the point where the two streams of liquid fuel impinged on each other. There was a band of discolored and oxidized metal where the flame played on the wall of the chamber, but no traces of erosion or incipient melting anywhere but on the bottom surface, where the erosion was quite serious, especially near the nozzle throats. Probably this was not real erosion in the full sense of the term, but rather the result of melting off of successive thin layers of metal, the heat not having had time to diffuse through its whole thickness. That this should have taken place near the nozzles, where the gas velocity was the greatest, was only natural, since the rate of heat transfer depended upon the speed with which insulating layers of gas were swept away from the metal surface, allowing new gas to flow past it.

4. The parachute failed to open and the parachute opening device did not get a fair test, because the horizontal flight of the rocket made it impossible for the parachute to open. The parachute was designed to open when the rocket acted as a freely falling body, a condition which was not realized in this flight.

This report on actual rocket flights in the early history of rocketry clearly illustrated the various difficulties small and large that had to be overcome before better performances could be obtained, and it is a fitting tribute to the early experimenters and pioneers in this most important field who had to devote their time and energy, even life itself, towards the advancement of the jet propelled engine and the future of rocketry.

The Latest Advancement in Rocketry

Not long ago when rocketry was still in its infancy, rocket researchers dreamed of nothing else but building a space-ship to fly to the moon. Although they were aware of the difficulties confronting them in designing such a craft, it was felt that by stirring up interest in rocketry, other eminent scientists might become sufficiently interested to help solve the problem of space travel.

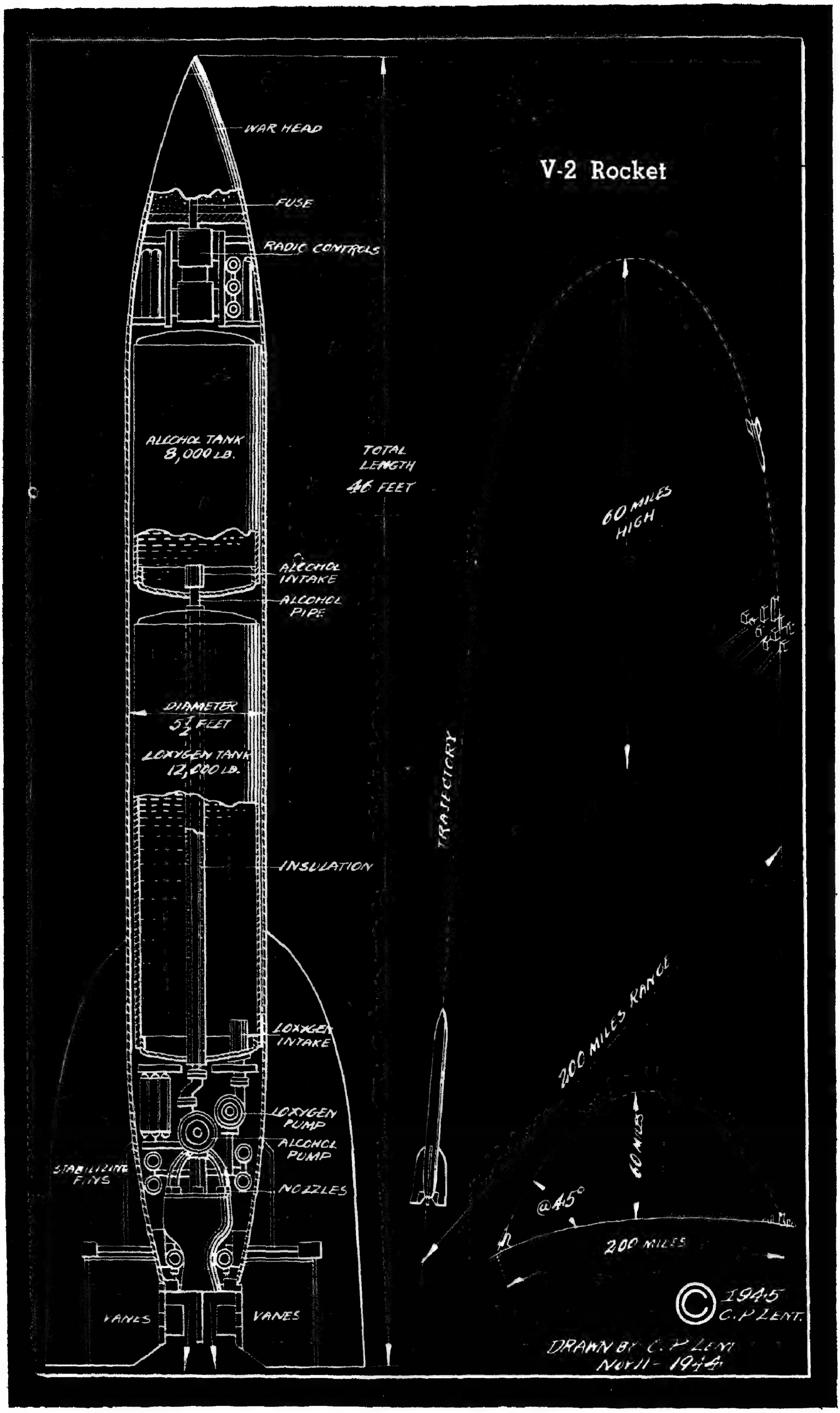
One group of experimenters, the active members of the American Rocket Society, have since then contributed a lot in this new field. So, also have the French and British Rocket Societies. However, the greatest development in rocket research has been advanced by the members of the German Rocket Socie.v.

In 1932, Mr. G. Edward Pendray, then the President of the A.R.S., traveled to Germany, France and to England to be present at a number of experiments made by the British and German Societies. From observation of a few trial shots, he reported some very interesting theories of space travel. He felt that here was an opportunity for the American experimentalists and scientists to show to the rest of the world what they could do.

The history of the work done by the American Rocket Society is well known by now. They were the first to develop many of the basic formulae and data now used in the construction of liquid propelled rockets. They and the eminent scientist, Dr. Robert H. Goddard, were the only people in this country who believed in the possibilities of rocketry. With the exception of a few experiments, the U. S. Govt. before this war did not show any active interest in rocketry, while the German Govt. not only experimented with, but extensively financied this new field...with the result that with the conflict in its full swing, the Germans are in position to show much greater advancemet in rocket design than the rest of the world. This fact has awakened the interest in rocketry in this country, and only recently, the Government built a replica of the German robot bomb, and tested it successfully.

Although the German Rocket Society was originally organized by a number of private individuals, as soon as their experiment showed any progress, the government took things in hand and forced the society to disband and become a government institution. The greater success of the Germans in developing rockets for their war effort must therefore be attributed to the fact that they had the financial support of the government. Such a step in our country would have been responsible for much greater advances in rocketry than we may now claim. Although the present U. S. societies should be left to exist as private organizations, the government should undertake to finance them. It is still not too late; and it has been reported that the Government has appropriated 65 million dollars for the construction of these weapons.

Let us consider the so-called V-1 or robot bomb, which is one of the latest developments of liquid propelled engines. It is really not a rocket in the true sense of the word, and in distinguishing it from rockets, it is known as a "hot air jet" engine. All rockets have jets, but the jet exhaust of the 'robot bomb' is the result of the combustion of gasoline and atmospheric air; while in a regular liquid fuel rocket, it is the result of combustion of gasoline and liquid oxygen. In short, the V-1 depends on atmospheric air for combustion of



V-2 Rocket

WAR HEAD
FUSE
RADIO CONTROLS
ALCOHOL TANK 8,000 LB.
TOTAL LENGTH 46 FEET
ALCOHOL INTAKE
ALCOHOL PIPE
DIAMETER 5½ FEET
LOXYGEN TANK 12,000 LB.
INSULATION
LOXYGEN INTAKE
LOXYGEN PUMP
ALCOHOL PUMP
STABILIZING FINS
NOZZLES
VANES
VANES
TRAJECTORY
60 MILES HIGH
200 MILES RANGE
60 MILES
@45°
200 MILES

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DRAWN BY C.P. LENT
Nov 11 - 1944

The V-2 is 46 feet long and 5½ feet in diameter. The capacity of the alcohol tank is 8000 gallons, while the capacity of the liquid oxygen tank is 12,000. It is provided with a complex pumping mechanism for the injection of the alcohol and oxygen into the combustion chamber. It is only a guess, but presumably the combustion chamber operates on a pressure of 300 to 500 pounds per square inch. Therefore, the pumps must be operated at somewhat higher pressure. The combustion chamber has a plurality of exhaust nozzles (15 to 25) of comparatively small diameter (2 to 3 inches). The motor, generally speaking is a degenerative motor, i.e., is it cooled through the fuel by means of appropriate cooling jacketing. The degenerative construction of the nozzle prevents the burning out of the motor.

The rocket travels at 3000 miles per hour, which is faster than sound —too fast to be heard. So, when it strikes the target, the sound arrives after the rocket hits the target. It has a range of 200 miles and a trajectory of 60 miles. Although it travels the short distance of 200 miles in only five minutes, it could fly much farther by being equipped with larger fuel tanks, but of lighter construction, and with a decreased payload, which in this case is 1000 pounds of explosives.

The rocket is launched vertically at a 45° inclination from a concrete platform. Turbines operated by super-heated steam initally operate the liquid oxygen and alcohol pumps. The mixture is ignited from some distance by electric means and the rocket is ready to take off. One minute after launching, the fuel is shut off by radio control or by means of pre-set instruments. The time at which the fuel is shut off determines the range of the rocket.

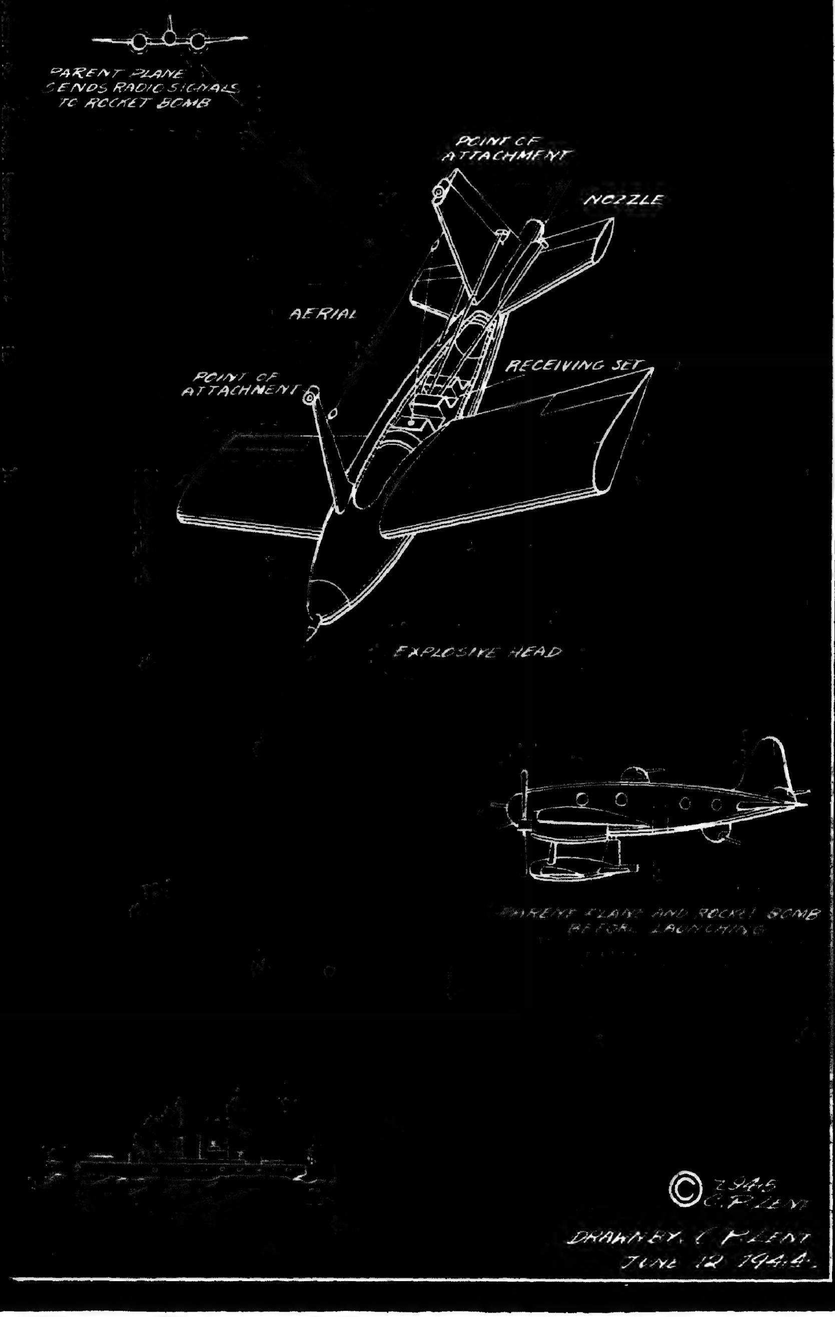
Scrutinizing carefully recent reports of the British Admiralty and the British Rocket Society, one fact stands out—namely, that the V-2 has great future possibilities for commercial travel, but for military use, it is very inaccurate. Even with many months of target practice, the Germans have not achieved any accuracy.

In any event, rocket research was not initiated for the benefit of the war lords. When the pioneers of this new field dreamed of flying to the moon, they imagined that this would be done in the interests of science and industry. Not-withstanding the fact that rockets, up to now, have been used exclusively for destructive purposes, they will be used more beneficially in the years to come after this conflict. Even now, the U. S. Govt. is experimenting with passenger class of planes operated by rockets and hot air jets; and it is not impossible that in the very near future (10 to 20 years from now) scientists of the world will be in position to construct a craft that will leave the earth and reach some other planet.

It is a matter of common observation that when we hurl an object up into the air, it invariably descends to earth again. Even shells, shot away from the earth from the most powerful guns we possess, never fail to return. But calculations show that if we could impart a velocity of some 25,000 miles an hour (more exactly 6.66 miles a second) to a shell, or another object, it would not return to earth. Its continuous speed would be sufficient to overcome the attracttion of the earth, and it would escape, never to return. This was the principle of Jules Verne's projectile. But as we have seen, in actual practice, the idea is not feasible. In passing through the earth's atmosphere

Rocket Bomb

New Glider Weapon



PARENT PLANE SENDS RADIO SIGNALS TO ROCKET BOMB
POINT OF ATTACHMENT
NOZZLE
AERIAL
RECEIVING SET
POINT OF ATTACHMENT
EXPLOSIVE HEAD
PARENT PLANE AND ROCKET BOMB BEFORE LAUNCHING

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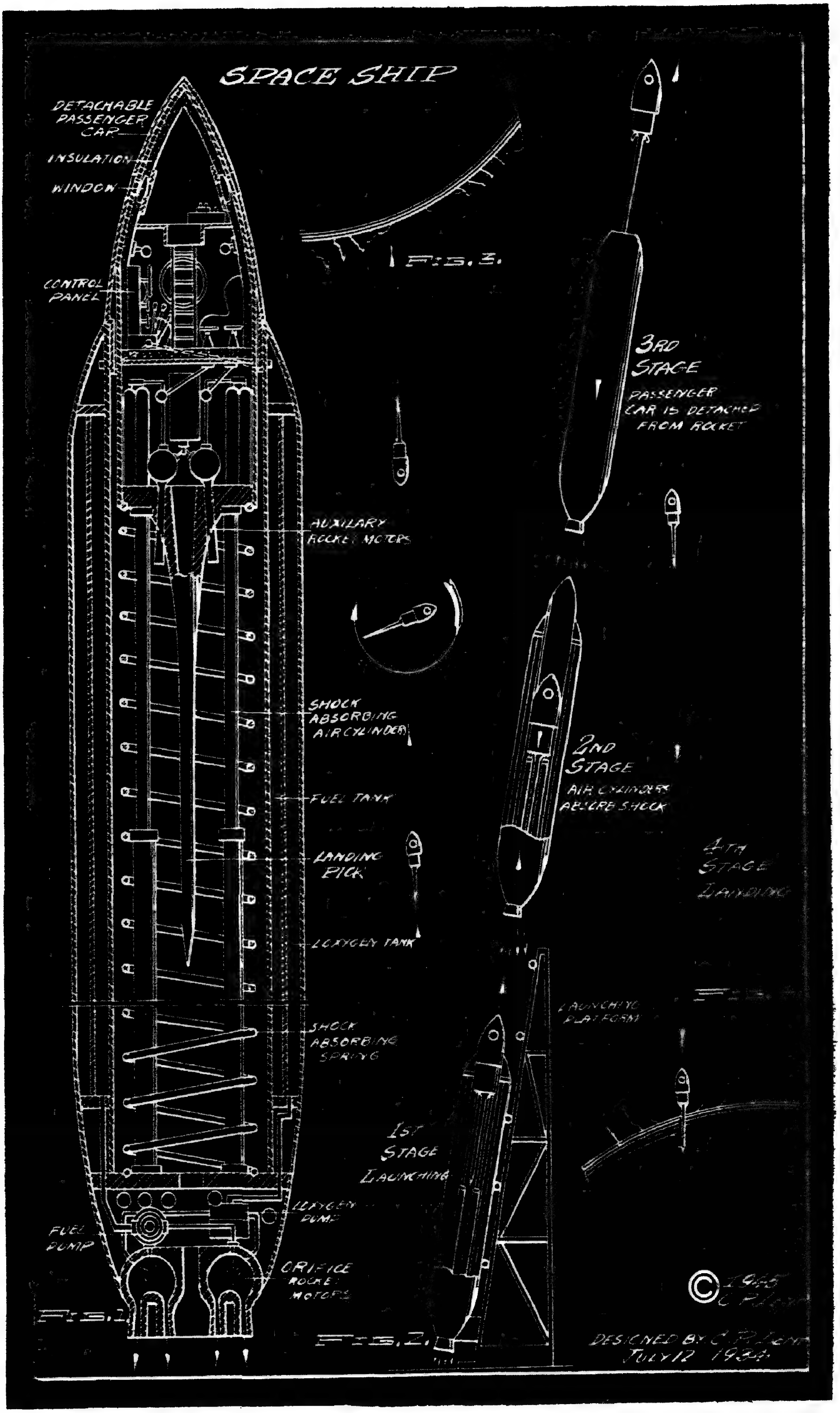
DRAWN BY. C. P. LENT
JUNE 12 1944.


SPACE SHIP
DETACHABLE PASSENGER CAR
INSULATION
WINDOW
CONTROL PANEL
AUXILARY ROCKET MOTORS
SHOCK ABSORBING AIR CYLINDERS
FUEL TANK
LANDING PICK
LOXYGEN TANK
SHOCK ABSORBING SPRING
LOXYGEN PUMP
FUEL PUMP
ORIFICE ROCKET MOTORS
FIG. 1
FIG. 2.
FIG. 3.
3RD STAGE
PASSENGER CAR IS DETACHED FROM ROCKET
2ND STAGE
AIR CYLINDERS ABSORB SHOCK
4TH STAGE
LANDING
LAUNCHING PLATFORM
1ST STAGE
LAUNCHING
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DESIGNED BY C. P. LEN
JULY 12 1934

its propelant, while a rocket is independent thereof. A rocket can fly in a vacuum, while the robot bomb would not rise above the atmosphere, and therefore, its flying efficiency is small.

The V-1 is a glider jet-propelled craft. It consists of a streamlined fusilage varying in length from 15′ to 25 feet with a diameter of 2 to 3 feet. Its wings have a spread of 25 feet; it has short tail fins and a substantially large rudder. Upon the upper portion of the fusilage, a long tubular motor comprising the combustion chamber; and nozzle or jet is open in the rear; the front is constricted by a plurality of vane-shaped flaps.

The fusilage of the V-1 contains a pair of spherical liquid oxygen tanks, and the wings hold the fuel tanks. Appropriate piping connections lead from the fuel tanks to the jet motor above the fusilage, while secondary tubing leads from the liquid oxygen tanks to a mechanism which operates the rudders of the latter, being under the control of a gyroscope.

The vane-flaps in the front portion of the motor substantially restrict the passage of outside air within the combustion chamber, but as the robot travels through the air, the vanes vibrate and successively close and open with the passage of air into the motor. The gasoline entering the chamber is vaporized through special nozzles, and as it is mixed with the air, it is ignited by a spark plug. To start the bomb, it is required to ignite the mixture only once. Successive explosions take care of themselves.

The robot is launched from an inclined ramp. Auxiliary liquid oxygen bottles provide the initial oxygen needed to start the motor and, once the robot leaves the ramp, the onrushing air enters the motor through the vanes to provide the oxygen for further explosions. At every explosion the vanes close automatically... and open again as soon as the exhaust gases leaves the nozzle and the pressure within the motor is low.

The new robot developed in this country, in addition to a ramp, utilizes a booster charge which helps the robot to rise from the ramp. The booster is consequently discharged and the rocket goes on its way unassisted.

Although this description of the robot bomb is not complete, the reader will appreciate the fact that there are many other things pertaining to its design and operation which are of secret nature and cannot be told, at least not during wartime, but what information which has been released is of interest to the public.

The use in this war of the V-2, which is another important development in liquid-propelled rockets, was of much greater surprise to the scientists all over the world than the use of the V-1. The V-1 is a simple device compared to the V-2. Therefore, one wonders how the Germans, with the war on their hands, would have found the time to experiment with and build such vast rockets for the mere pleasure of shooting them aimlessly against an unseen target.

In comparison to the V-1, the V-2 ship is a pure rocket. The V-2 is equipped with a fuel (gasoline or alcohol—both ingredients used to propel the rocket) cylinder and a liquid oxygen cylinder. Thus, it can rise above the rarified air of the upper strata, and with enough fuel could leave the earth.

Therefore, that dream of the early experimenters, which seemed so fantastic several years ago, is now possible.

THE THEORY OF ROCKET OPERATION

It is apparent from a perusal of rocket literature that the theory of rocket reaction is not generally understood by rocket experimenters. Various formulas and equations are given, which, however, lead to results not in agreement with each other. There is no reason why this should be so, for, while the serious study of rocket development is of comparatively recent origin, the underlying laws of physics and thermodynamics have been known for a long time.

Moreover, from the standpoint of practical design, the action of a rocket nozzle differs from that of the turbine nozzle only in so far as the pressure and temperature conditions of the ejected fluid are involved, while the principles of operation are identical.

In view of the above facts, as well as results derived from a series of tests the writer thought it desirable to elucidate the theory of rocket operation based on accepted thermodynamical laws, both in order to clarify the situation, and to furnish a standard of performance of an ideal rocket motor, whereby the performance of real rocket motors may be judged. From the theoretical standpoint and from results obtainable from rocket flights.

The action of a rocket depends upon a fundamental law of physics, namely the fact that every action has an equal and opposite reaction. ($M\ V = m\ v$).

Let us consider a rocket, not acted upon by a gravitational field.

Let: M represent the mass of the rocket
- dm the differential mass of exit gas ejected during an infinitely short period of time (dt)
- dV the increment in rocket velocity due to ejection of dm.
- v the gas jet velocity.
- α the acceleration or rocket.

Equating momenta:

$M\,dV = v\,dm$
$M\,dV/dt = v\,dm/dt$ (Dividing through by dt)
$M\,\alpha = v\,dm/dt$ (dV/dt acceleration)
$R = v\,dm/dt$ ($M\,\alpha$ Force Reaction)

Since dm/dt is the mass of gas flow per second, we can write:

Reaction, lbs. = (1/32.2) (Jet velocity, ft. per sec.) (Wt. of flow, lbs. per sec.) (No. 1—equation).

This is the fundamental equation for all jet reactions.

An examination of equation 'No. 1' will show that the reaction may be increased by increasing the jet velocity, or the weight of flow, or both. Some attempts have been made to increase this reaction by introducing heavy inert materials into the jet, such as molten lead mercury, or even solid projectiles. It will be shown later that such expedients are incapable of increasing the reaction.

The equation 'No. 1' : $R = (v\ w)/g$ involves terms whose value we do not generally know so we cannot apply it directly. Let us first consider liquid jets, under such conditions that the liquid is always below its boiling point. The theory of such jets is relatively simple; no thermal changes are involved.

Let:

v represent jet velocity (ft. per sec.)
w the weight of flow (lbs. per sec.)
h the head in feet (an alternative measure for pressure)
d the density of liquid (lbs. per sq. in.)
A the nozzle area (square inch)
p the gage pressure (lbs. per sq. inch)
g the gravity (lbs. per sq. inch)

Then:

$$v = 2gh$$
$$h = p/12d$$
$$v = 2g\ (p/12d)$$
$$\text{and } w = 12\ A\ v\ d$$
$$\text{in '1' } R = 2g\ (p12d)\ 12\ A\ d/g$$
$$R = 2\ pA \text{ ``2'' — equation}$$

As all practical rockets use gas jets for their propulsion, except the powder rockets, where the jet may in some cases contain a small amount of solids as a by-product of combustion, it is the action of gas jets which is of primary interest to the rocket-builder. Their theory will be discussed below. The writer wishes to point out in this connection that "Engineering Thermodynamics" by **Lucke** has been used as a reference book. Some equations have been directly reproduced from that volume, while others have been transformed and rederived to make them applicable to rocket problems.

According to Boyle's Law the pressure—volume product of a gas is equal to a constant, to wit

This law applies to isothermal conditions, i.e. those where heat is either added to or removed from the gas, so as to maintain it always at a constant temperature. In practice this is very seldom the case. Pressure—volume changes are always accompanied by thermal ones, which in turn affect the resultant pressure or volume, and thus introduce a complication. These changes follow the experimental law, which states:

$$P_1 V_1^s = P_2 V_2^s = K$$

The value of the exponent "s" has been experimentally determined for a variety of gases and conditions. In a rocket nozzle the expansion takes place under substantially adiabatic conditions, or, in other words, at a constant entropy. Under such conditions the exponent s is equal to 1.4 for air, while for CO_2 and for superheated steam, it is 1.3. Since rocket exhaust, with common liquid fuels, consists chiefly of CO_2 and superheated steam, we may assume the value of s to be very close to 1.3.

The velocity of a gas jet expending from an initial pressure P_1 to a final pressure P_2, is given by Zeuner's Equation.

$$= \sqrt{2g \frac{s}{s-1} P_1 V_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{s-1}{s}}\right]}$$

The weight of flow will be:

$$w = \frac{A}{V_1} \left(\frac{2}{s+1}\right)^{\frac{1}{s-1}} \sqrt{2g \frac{s}{s-1} P_1 V_1 \left(1 - \frac{2}{s+1}\right)}$$

lb.s per sec.

where: P_1 represents absolute initial pressure, lbs. per sq. feet.

P_2 the absolute final pressure, lbs. per sq. feet.

V_1 the initial specific volume of gas, cubic ft. per lb.

V_2 the final

A nozzle area, square feet.

Now it is a curious fact that at a certain pressure ratio of P_2 to P_1 a critical condition is reached where the maximum weight of flow occurs. This takes place when:

$$\left(\frac{P_2}{P_1}\right) = \left(\frac{2}{s+1}\right)^{s}$$

To quote Lucke: . . . "This result is quite remarkable and is verified by experiment reasonably closely. It shows that, contrary to expectation, the weight of efflux from nozzles will not continuously and regularly increase with increasing differences in pressure, but for a given initial pressure the weight discharged per second will have reached its limit when the final pressure has been diminished to a certain fraction of the initial, and any further decrease of the discharge pressure will not increase the flow through an orifice of a given area."

For most common values of s this maximum flow occurs when (P_2/P_1) is between .5 and .6.

It is also interesting to note that in every orifice, or nozzle there is a point where the pressure falls to this critical value of itself, and that the gas acquires a certain fixed velocity at that point which is the velocity of sound in that medium. In a properly designed nozzle, further expansion, with an increase in velocity takes place beyond the critical point.

For any pressure drop greater than the critical one, the weight of flow will be as follows:

$$w = \frac{A}{V_1} \left(\frac{P_2}{P_1}\right)^{\frac{1}{s}} \sqrt{2g \frac{s}{s-1} P_1 V_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{s-1}{s}}\right]}$$

pounds per sec.

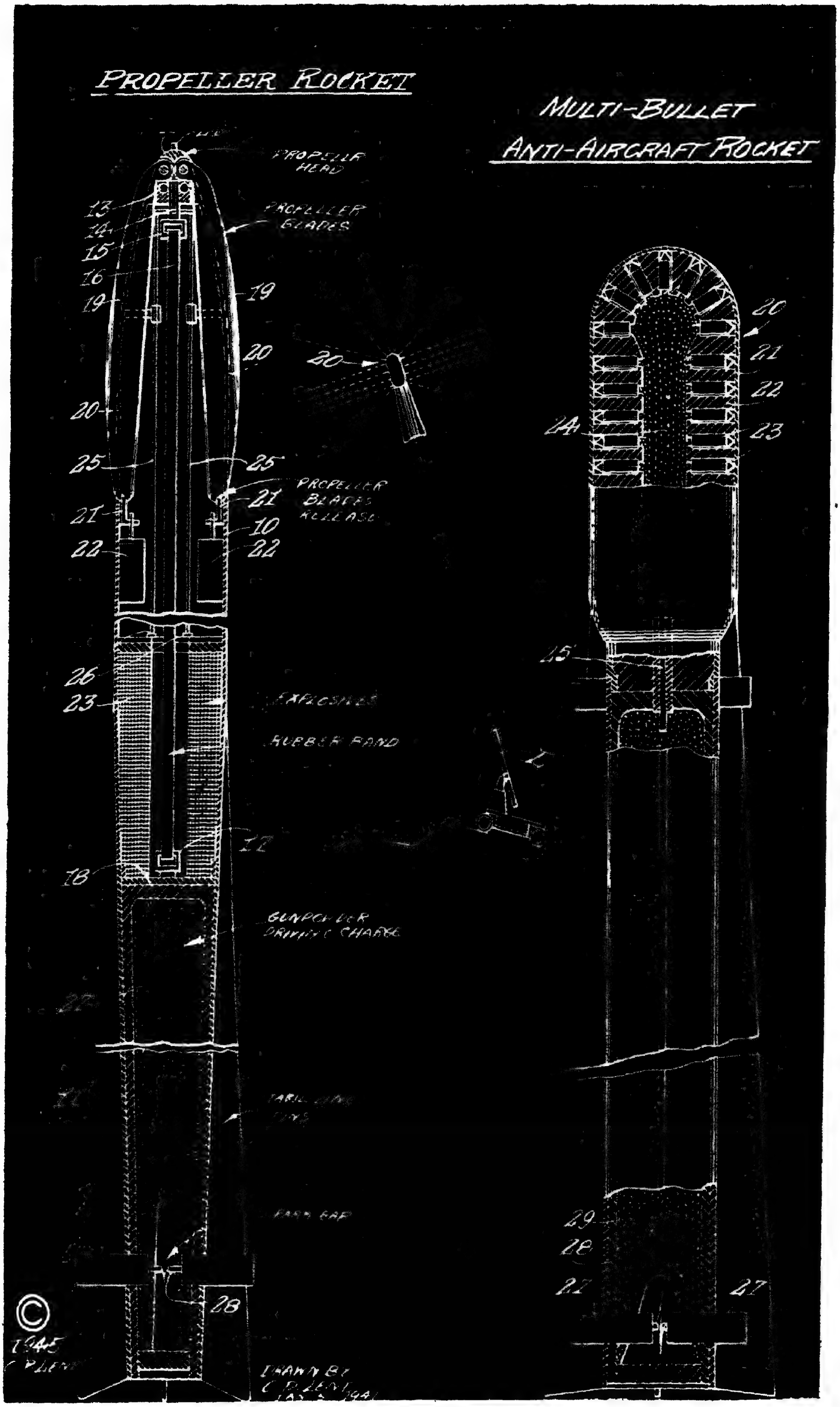
We can now combine the equation for velocity and for the weight of flow, and evaluate the reaction developed by the nozzle.

$$R = 2AP_1 \sqrt{1 - \left(\frac{P_2}{P_1}\right)^{\frac{s-1}{s}}} \sqrt{\left(\frac{2}{s+1}\right)^{\frac{2}{s-1}} \frac{s^2}{s^2-1}}$$

lbs.

In this equation, we may express the pressures in pounds per square inch, while A is the throat area of the nozzle in square inches. The pressures are absolute pressures = (gage plus 1 atmosphere).

This equation applies to an ideal case, where all combustion takes place in the firing chamber and only the products of combustion are ejected through the nozzle without frictional reheat or sidewise dissipation. Of course these conditions cannot be fully realized in practice. Still, it is possible to make very nearly perfect nozzles. Certain steam turbine nozzles have developed a Rankine Cycle efficience of 97 to over 98 per cent, when working against very low back pressure.



PROPELLER ROCKET

MULTI-BULLET ANTI-AIRCRAFT ROCKET

PROPELLER HEAD
PROPELLER BLADES
13
14
15
16
19
19
20
20
20
25
25
PROPELLER BLADES RELEASE
21
21
10
22
22
26
23
EXPLOSIVES
RUBBER BAND
17
18
GUNPOWDER DRIVING CHARGE
28
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1945
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DRAWN BY
C. P. LENT

at such a speed, the projectile would inevitably be rendered incandescent through friction. Moreover, such a projectile could not transport living things. The accelaration would kill them even before they were burnt to death.

Through the centuries there have been advanced many suggestions pertaining to possibilities for space travel and the design of a craft to leave the earth.

The plate illustrates an imaginary design for such a craft. Note that it consists of an elongated cylindrical body has a hollow space occupied by the passenger car. The rocket is slightly with-held within the space and is supported by a number of compressed air cylinders and possibly a coil spring. Both cylinders and coil spring serve as shock absorbers. The lower portion of the space ship is equipped with the rocket pumps and other devices required to propel the craft. The passenger car is equipped with auxiliary rocket motors and a landing pick.

Four stages of the launching and landing of the rocket are also shown. In stage 1. the ship is launched from an upright launching platform.

As it gathers speed, the passenger car, which is supported by the shock-absorbing mechanism, is forced into the hollow space provided within the cylinder. This position corresponds to stage 2. in the drawing.

The rocket leaves the gravitation of the earth and brushes the gravitation of another planet. By the time this is accomplished, the fuel has been consumed, and the empty tanks are excess weight. So, the passenger car is disconnected from the rest of the rocket and it continues on it way, while the portion of the rocket comprising the fuel cylinders drops into space. This corresponds to stage 3. in the drawing.

When the passenger car reaches its objectives and is again under the influence of gravitation, it begins to turn around until the landing pick, which is heavier than the rest of the passenger car, faces the planet. As the car approaches the surfaces the auxiliary motors go into operation—this, in order to reduce the shock. The landing pick imbeds itself in the ground, allowing the passenger car to land in an upright position.

The design of the space ship as shown, can be changed to conform to any or all for space travel. It is understood that this is only illustrated as an example.

If instead of a conventional flared nozzle, we should use a plain orifice or hole in the wall of the rocket motor, we would still obtain some reaction from it.

The jet, however, would build up a back pressure on the outside of the orifice, limiting the velocity, as already explained, due to the critical condition, with the result that a large fraction of the potential energy of the gas would be uselessly dissipated. Furthermore, if sharp corners exist, the net area available for gas passage may be as low as 60 per cent of the gross area.

Ideally, a nozzle should be so designed that it will discharge the gas axially and at the pressure of the surrounding medium, without frictional reheat. If the mouth is too small, the full expansion is not realized; if, on the other hand, the mouth is too large, we have overexpansion with the result that recompression takes place, setting up waves, very detrimental to the successful operation of the nozzle. Too sudden an expansion of the nozzle causes the gas to bounce from side to side, producing frictional reheat, while too small an angle results in a long nozzle, which also causes increased friction.

For the determination of the expansion ratio, i.e., the ratio of the throat to the mouth of the nozzle, we can use Meyer's empirical equation.

$$\left(\frac{\text{Mouth Area}}{\text{Area}}\right) \begin{array}{ll} = .172\left(\frac{P_1}{P_2}\right) + .7 & \left(\text{when } \frac{P_1}{P_2} < 25\right) \\ = .175\left(\frac{P_1}{P_2}\right)^{.54} + .7 & \left(\text{when } \frac{P_1}{P_2} > 25\right) \end{array}$$

The flare angle of the nozzle is not well established theoretically. Various angles are used, with not so much difference as might be expected. Angles between 10 degrees and 20 degrees are most commonly used in steam turbine practice. It should be borne in mind in this connection, that a rocket is subject to variable conditions. The tank pressure will gradually decrease as the fuel is used up, while the back pressure will vary from that of sea level to that prevailing at some high altitude, provided the rocket goes up that far.

In the design of rocket nozzles it is advisable to avoid hair-splitting and rather exercise some sound engineering judgment in selecting an average condition.

Example

Design a nozzle for a rocket working at 300 pounds chamber pressure, discharging to atmosphere at sea level, having a throat diameter of ½ inch. If the weight is 20 pounds what will be the acceleration of the rocket?

$P_1/P_2 = 315/15 = 21$

Then mouth area/throat area = .172 x 21 plus .7 = 4.31

Throat area (1/2) = .196 in^2

Mouth area = 4.31 x .196 equals .845 in^2

Mouth diameter = 1.04 in.

Difference in radii = .27 in.

Assuming 12 degree flare angle (included) length = cot 6 degrees x .27 equals 2.57 in.

Nozzle reaction by equation (3): = 2 x .196 x 315 x .710 x .950 = 83.4 pounds

Acceleration = (83.4-20)/20xg equals 102 ft. per sec.

The problems that face the rocket designer in choosing materials resolve themselves into two divisions:

(1) Selecting the materials for the blast chamber.

(2) Selecting the materials for the fuel tanks.

The ideal blast chamber materials should have these properties:

Good thermal conductivity
High melting point
High specific ten. strength at high temperatures
Good wearing qualities against the erosion of exhaust gases.
Practical fabrication possibilities.

As all the qualities desired cannot be found in one metal or alloy, some must be balanced out in favor of others.

For example the advantages in the greater strength and hardness of the alloyed metals may not be as desirable as the higher melting points and thermal conductivity found in the same ones unalloyed. Further, all heat treatable and age hardening alloys lose their superiorities in strength at the higher temperatures.

Even though the temperature of the ordinary rocket flame (oxy-gasoline) is

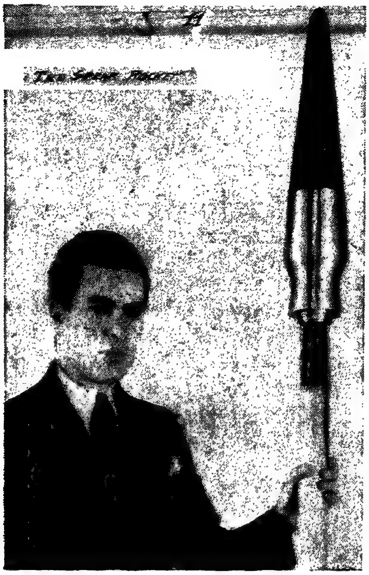


FIG. 50
A photograph of the head of the Spear Rocket built by the author.

2000 degrees C., it has been found preferable to use a blast chamber of moderate melting point like one made of aluminum, rather than one of steel with a higher melting point but far inferior in thermal conductivity. This becomes obvious when it is realized that a material with a melting point below that of the flame temperature it comes in contact with cannot be expected to remain solid unless it can conduct this heat away quickly. For this reason, copper can also serve well to form a blast chamber.

For best results and before using nozzles the latter are tested upon test stands such as shown in Figures 20, 46 and 44. This practice is followed by all advanced experimenters and by the A.R.S.

Aluminum blast chambers have superiorities in other ways that may appear obscure but which nevertheless are very real.

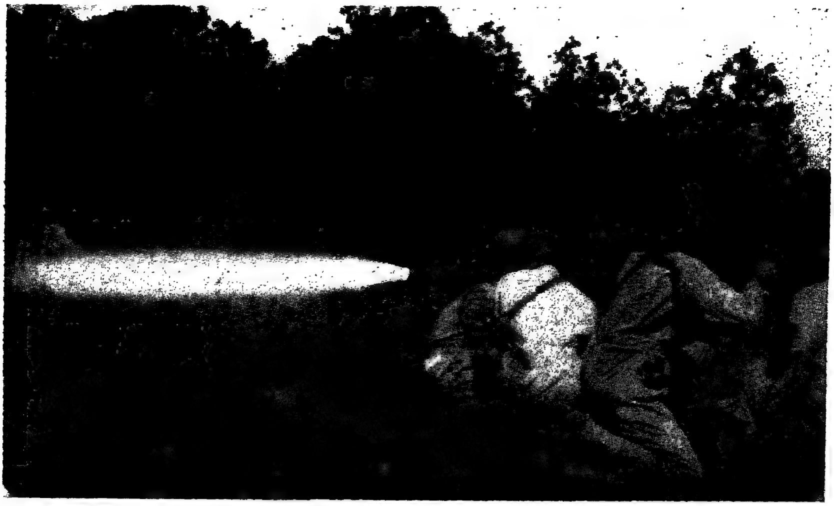
As aluminum is three times lighter than most comercial metals, motors of it can have about three times more volume to act as a heat reservoir, than would be possible with the others. Experience with rocket motors have shown this to be very important.

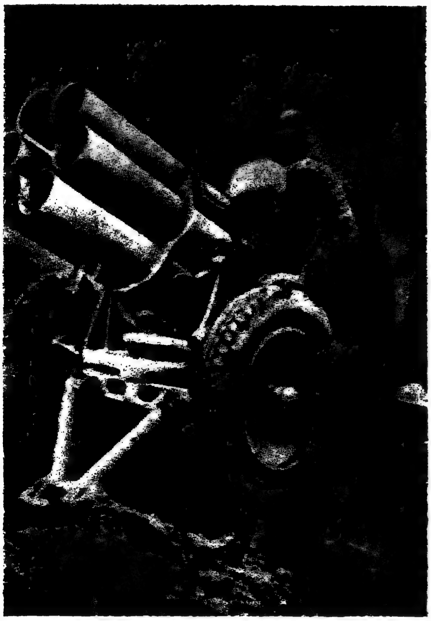
Also, the protection afforded by the oxide of aluminum is so good that it never allows oxidation to advance beyond a thin layer. (This feature has certain disadvantages, however, for a heavy layer of Alumina, which has almost the hardness of diamond and a high melting point would be highly useful in resisting the erosive flow of hot gases.) Titanium and to some extent Beryllium, have this same ability to form refractory, hard, tenacious oxides.

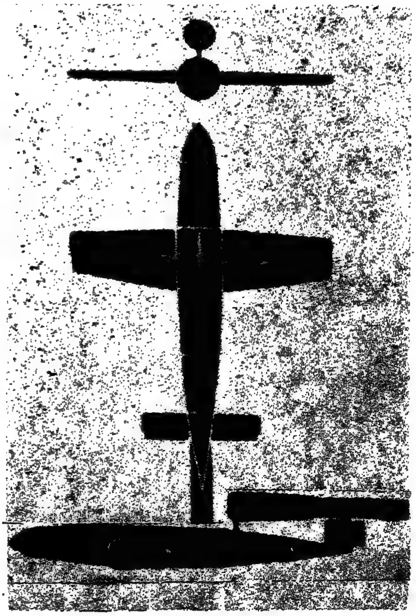
Copper, common steels and magnesium alloys, form powdery oxides with pracitcally no structural strength or protective properties.

Stellite has been suggested as a good alloy for a rocket motor. It has a hardness of 7, and high tensile strength which it tends to hold at elevated temperatures, but it must be rejected on three points: poor thermal properties, melting point be given consideration in a discussion of rocket materials: refractories and plastics.

The only refractory higher in melting point than Tungsten is graphite. Those, other than graphite, that exceed Molybdenum do not do so by any great margin. All are poor conductors of heat, the best, Graphite, having a resistance 800 times greater than copper. All are either brittle or poor in tensile strength at high temperatures with graphite again coming out highest. A transparent fused quartz motor also remains as a possibility and would be exceedingly useful in studying gas

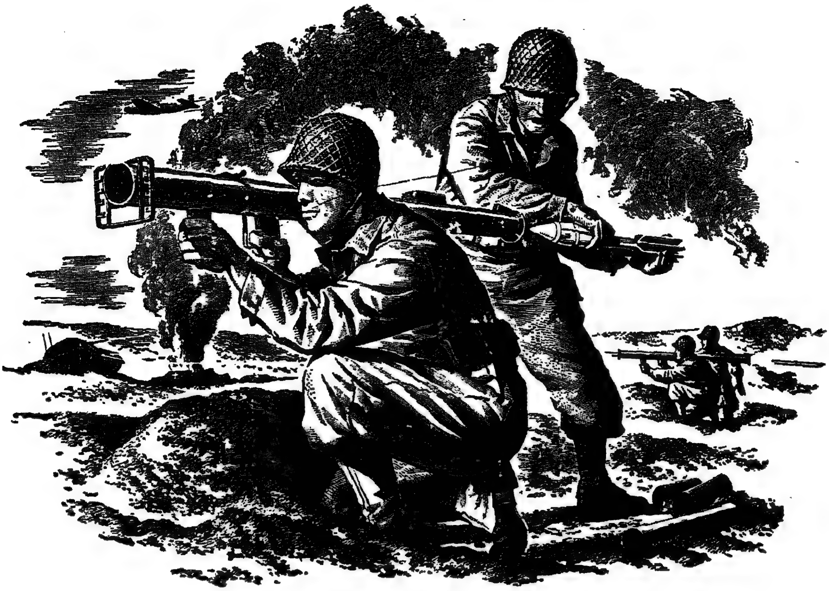


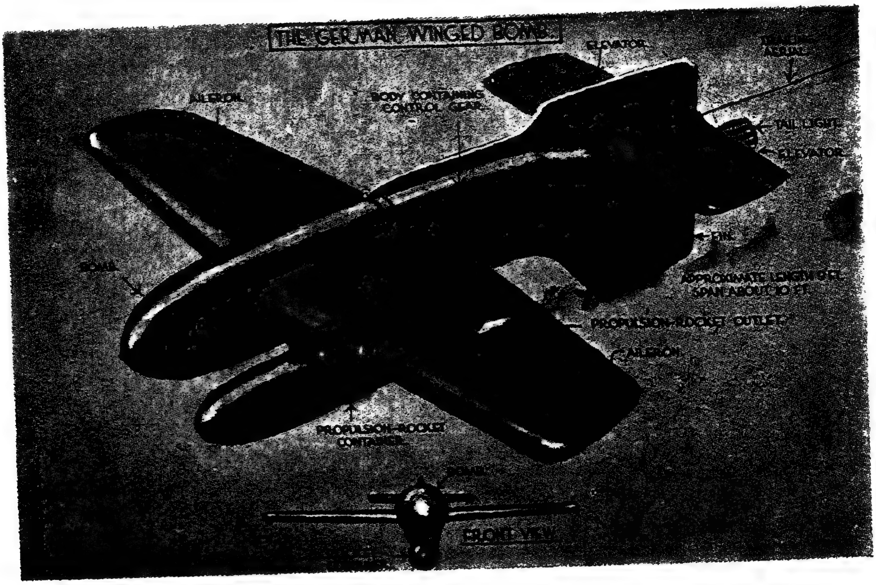




III

These plates show a number of uses that dry fuel rockets found in the present war. Top view is the Pyrotechnic Piledriver, the slender handful of destruction which has become a great favorite with the American troops, The burning of the driving powder of the projectile's rocket charge takes place within the launching tube, there is no reaction felt by the Bazookaman. The photograph lower left is a German rocket launcher. This device is light, easy to manufacture and requires little maintenance; the rocket shells are fired from the six tubes shown mounted upon a wheeled chassis. The picture lower right is the terrible Robot Bomb employed by the Germans. It is around 25 feet long with a wing span of 16 feet and carries a 1000 lb. explosive charge in its nose. It is reported that although the V-1 models can fly around 200 miles, the V-2 models will fly 500 miles and more. The Robot Bomb is driven by an intermittent jet motor located over the body proper. It is operated by gasoline and atmospheric air.




THE GERMAN WINGED BOMB
ELEVATOR
TRAILING AERIAL
AILERON
BODY CONTAINING CONTROL GEAR
TAIL LIGHT
ELEVATOR
FIN
BOMB
APPROXIMATE LENGTH 9 FT. SPAN ABOUT 10 FT.
PROPULSION-ROCKET OUTLET
AILERON
PROPULSION-ROCKET CONTAINER
BOMB
FRONT VIEW

IV

Above is a very interesting line cut drawing used by a large firm in one of their advertisements. "Two Man Tornado". The manner the gun is loaded by the rocket projectile is clearly shown in the cut. Below is an artist's view of the long-talked of weapon of destruction, the radio directed Rocket Bomb reported by eye-witnesses. While in the Robot Bomb used now by the Germans the reaction motor is located on the top of the missile, in this case it is placed under it.

TABLE I

Blast Chamber Metals

Metal	Gr. Sp.	°C M. P.	Cu. 100 thermal conduct	hard- ness	ten. strength lbs-in²	ten. str. at 1000°C	nature of oxide at high temp.
Aluminum	2.7	658	55	2.9	10,000	(Liquid)	hard
Duralimin	2.8	550	30	3.5	65,000	(Liquid)	hard
Copper	8.9	1083	100	3.5	30,000	Low	Powdery
Ber. copper	8.2	864	40	5.	193,000	(Liquid)	Powdery
Iron	7.9	1525	15	4.5	40,000	Low	Powdery
Stainless Steel	7.8	1250	5	5.5	175,000	6,000 lbs.-in²	Partially refractory
Stellite	8.6	1250	1.5	7	255,000	24,000 lbs.-in²	Par. refra.
Molybdenum	10.2	2620	40	6.	300,000	50,000 lbs.-in²	Oxidizes very slowly
Tungsten	19.3	3370	45	7.	560,000	15,000 lbs.-in²	Oxidizes very slowly

Other Possibilities

Metal	Sp. Gr.	M. P.	Hard- ness	Thermal Conduct	Nature of oxide at high temperature
Beryllium	1.84	1280	6.5	10	Refractory but not protective
Titanium	4.8	1795	7.	40	Refractory, hard

ate specific gravity, it may well go to form a blast chamber able to withstand the Oxy-acetylene flame (4400°C)

Tungsten, although having a melting point 700 degrees higher, falls off very rapidly in tensile strength until at 1000°C it has only about one-third that of Molybdenum at the same temperature. So it can be seen that to design a motor to withstand a given pressure at this temperature, 6 times as much Tungsten would be required to give it the strength equal to one of Molybdenum. With advancing temperature the differences become more marked.

Other metals with high melting points, like Tantalum and those of the Platinum group, do not offer the advantages that either of the aforementioned do.

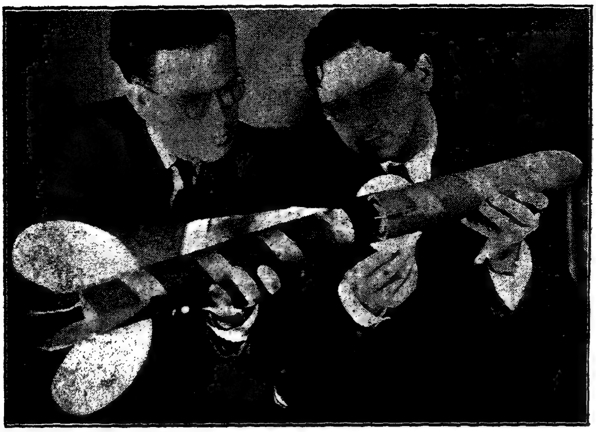


FIG. 51

A design of two-step motor. Note the two separate parts and the manner they are joined together. This is a gun-powder model.

Because Molybdenum and Tungsten cannot be safe, and become workable only at temperatures at which no other materials can be used to forge them, a method of sintering must be used to form them. The powdered metal is placed in the desired mold and then subjected to high temperatures and pressures. The intercrystalline friction created by this treatment causes a fusion of the powder, making the metal solid and homogenous.

As we have seen, the problem before the rocket designer in choosing materials resolves itself into two sections:

1. Materials for the blast chamber.
2. Materials for the fuel tanks.

The properties and characteristics of materials available for motor construction have been considered above.

The fuel tank materials should have these properties:

(1) High sp. ten. strength at low temperature.

(2) Low thermanl conductivity.

(3) Practical fabrication possibilities.

Fuel tanks made of beryllium-copper, stainless steel, duralimin, and dow metal, with the same strength and capacity would be about equal in weight, provided they were used to operate at ordinary temperatures. But at the temperature of liquid oxygen (—186°C) only aluminum copper and lead alloys appear to remain applicable.

Magnesium and Lithium alloys have not yet been investigated. Lithium (not satisfactorily alloyed as yet) if it follows lead in this respect as it does in other physical ones, may be superior to all in tensile strength at low temperatures.

Aluminum and copper alloys are the most workable. Aluminum, however, has this advantage, in that the safe working tolerances on parts made from it are 3 times greater than for copper, due to that much increase in the thickness of members.

The process of gas welding the new strong Duralimin alloys and Beryllium copper remains to be perfected, but welding in an induced atmosphere of hydrogen is possible in both cases and if a welding rod having the composition of the original alloy is used little strength will be lost at the welds after heat treatment.

Two other branches of substances must be given consideration in a discussion of rocket materials: refractories and plastics.

The only refractory higher in melting point than Tungsten is graphite. Those, other than graphite, that exceed Molybdenum do not do so by any great margin. All are poor conductors of heat, the best, Graphite, having a resistance 800 times greater than copper. All are either brittle or poor in tensile strength at high temperatures with graphite again coming out highest. A transparent fused quartz motor also remains as a possibility and would be exceedingly useful in studying gas flow and combustion not too high in temperature.

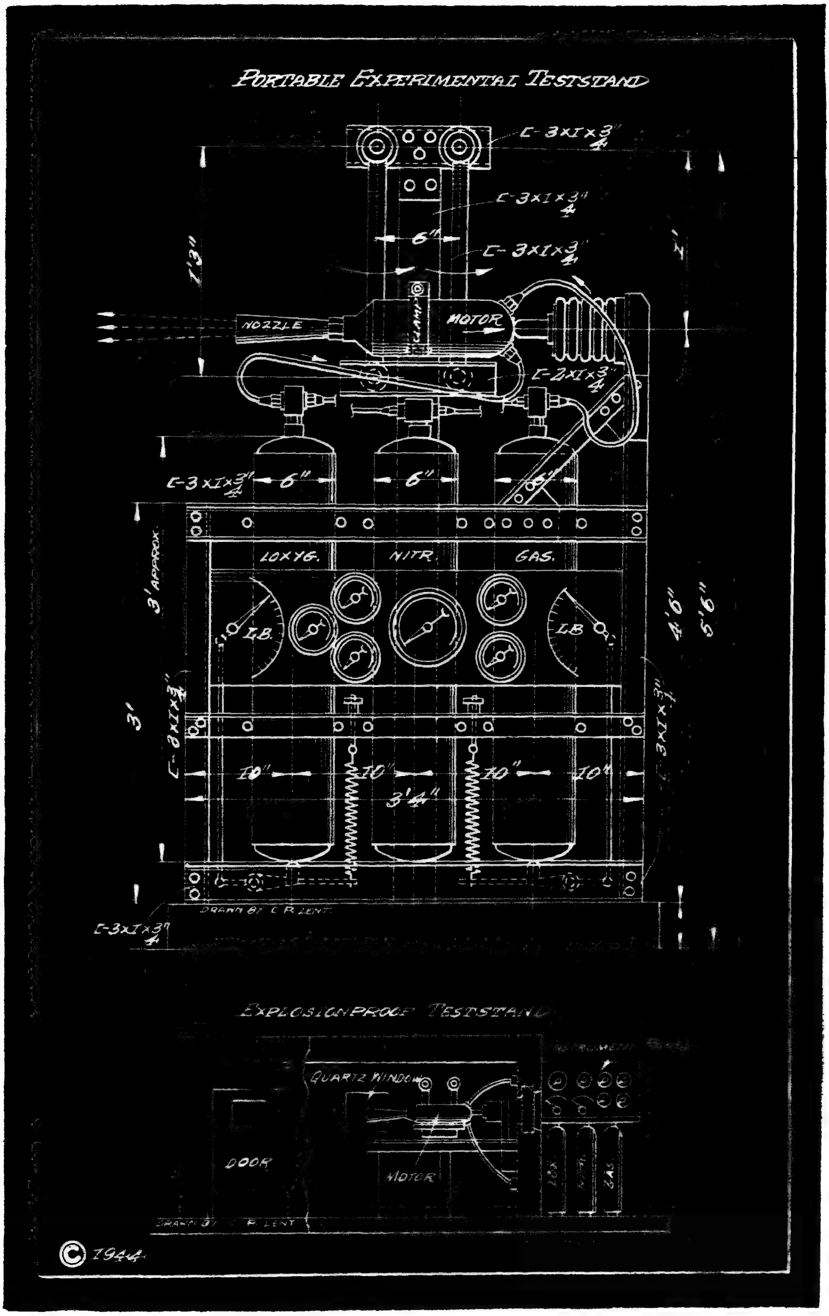

PORTABLE EXPERIMENTAL TESTSTAND
C-3x1x3/4"
C-3x1x3/4"
6"
C-3x1x3/4"
1'3"
NOZZLE
CLAMP
MOTOR
C-2x1x3/4"
C-3x1x3/4"
6"
6"
3' APPROX.
LOXYG.
NITR.
GAS.
LB.
LB
4'6"
5'6"
3'
C-3x1x3/4"
3x1x3/4"
10"
10"
10"
10"
3'4"
DRAWN BY C R LENT
C-3x1x3/4"
EXPLOSIONPROOF TESTSTAND
INSTRUMENT PANEL
QUARTZ WINDOW
DOOR
MOTOR
LOX
NITR
GAS
DRAWN BY C R LENT
© 1944

FIG. 49

Above is an elaborate portable test stand. It has three cylinders, one for the gasoline, another for the liquid oxygen and a third for nitrogen. The gasoline and the oxygen cylinders are hung on spring scales to show fuel consumption when making a test and are connected to the motor by a flexible tubing. The motor to be tested is hung upon a balanced scale and the thrust is measured by means of a bellows connected to a hydraulic gauge. Note all the various gauges upon the stand for measuring pressure, temperature, time of firing, etc. Below is a cross-section through a concreté explosion proof test stand. The panel where the recording instruments are located is on the outside of the chamber where the behavior of the motor can be observed through quartz windows in the wall.

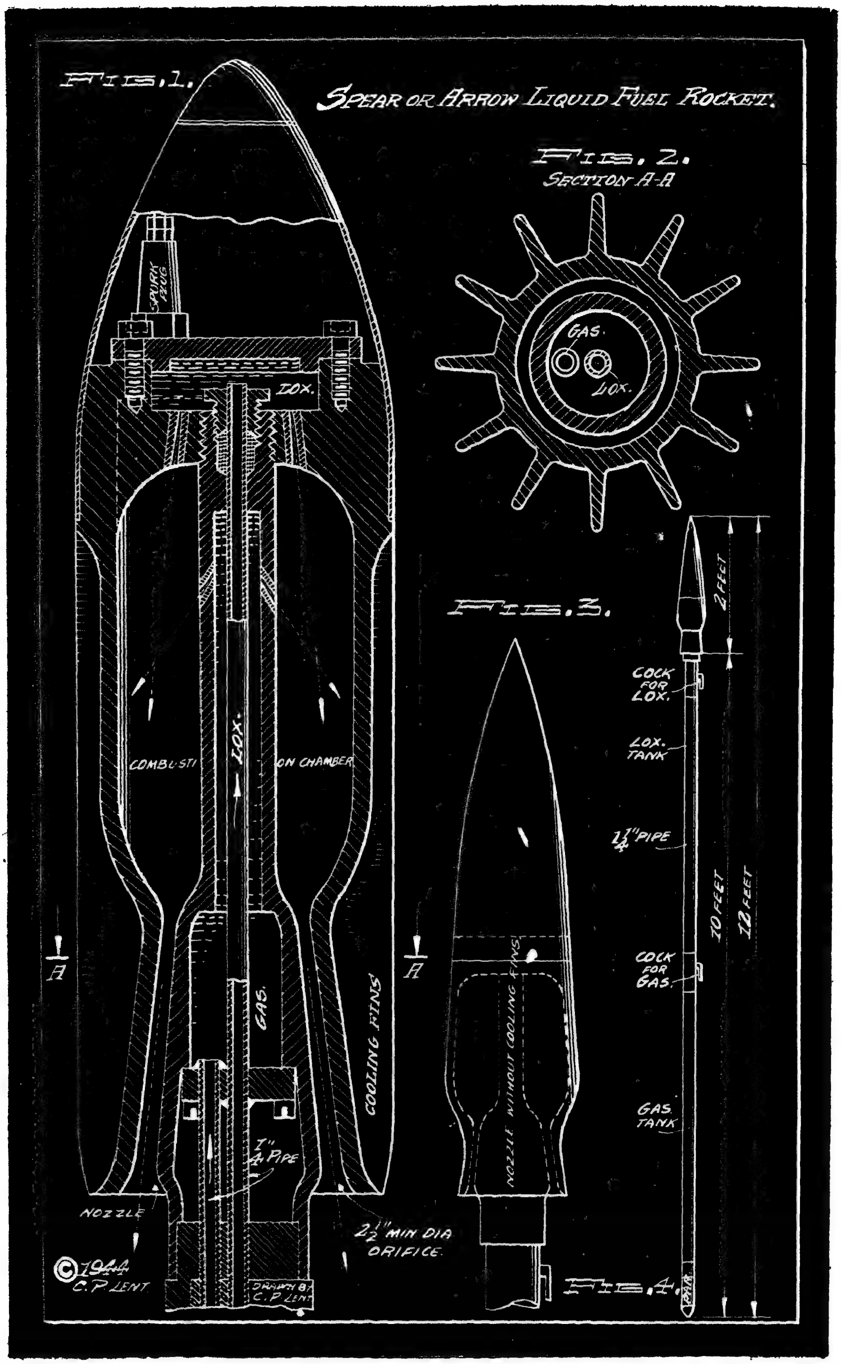


FIG. 1.
SPEAR OR ARROW LIQUID FUEL ROCKET.
FIG. 2.
SECTION A-A
GAS.
LOX.
SPARK PLUG
LOX.
COMBUSTION CHAMBER
LOX.
GAS.
COOLING FINS
A
A
1/4" PIPE
NOZZLE
2 1/2" MIN DIA ORIFICE
©1944 C.P. LENT
DRAWN BY C.P. LENT
FIG. 3.
NOZZLE WITHOUT COOLING FINS
FIG. 4.
2 FEET
COCK FOR LOX.
LOX. TANK
1 1/4" PIPE
10 FEET
12 FEET
COCK FOR GAS.
GAS. TANK

FIG. 56

A novel treatment of rocket construction is the one shown above built by the author. Note that the rocket proper has a spear or arrow shaped design. The motor shown in Fig. 1 has a skirt shape nozzle with a centrally located core. The nozzle in this case is the space left between the skirt and the core. A further new feature, is the manner in which the gasoline and the liquid oxygen is supplied to the motor. The motor has a plurality of cooling fins, see Fig. 2. Fig. 3 is the head of a spear rocket minus the cooling fins.

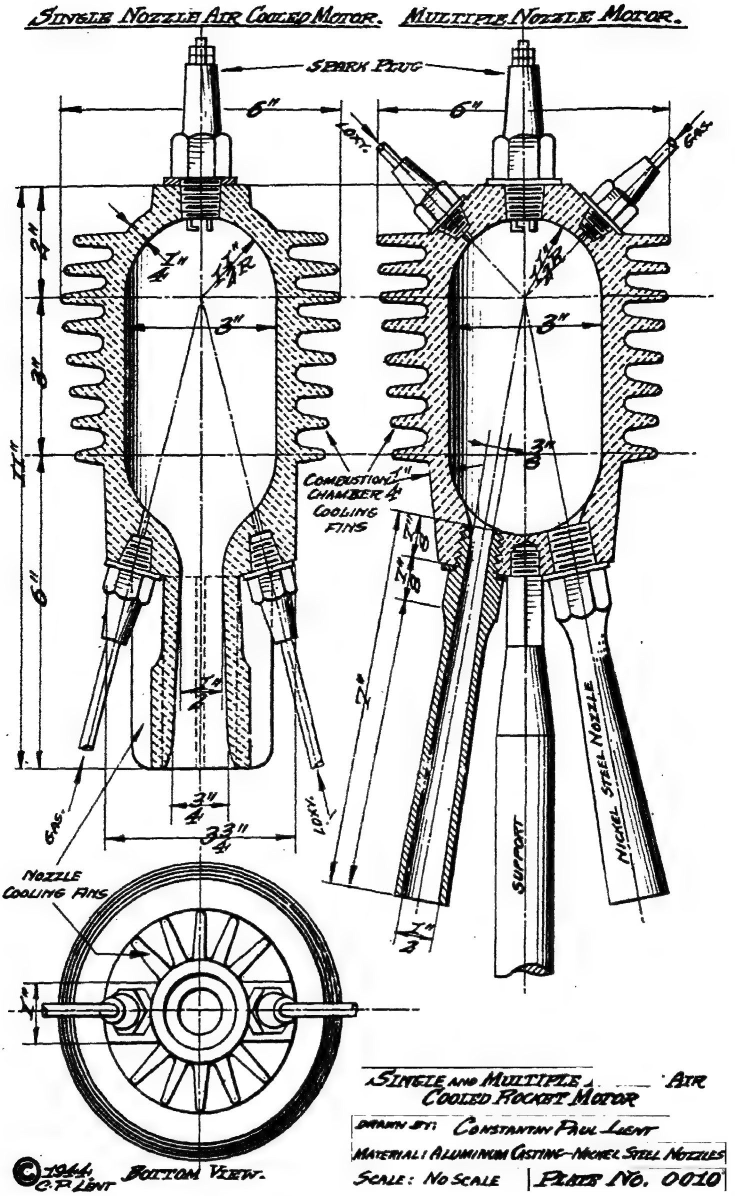

SINGLE NOZZLE AIR COOLED MOTOR.
MULTIPLE NOZZLE MOTOR.
SPARK PLUG
6"
6"
LOXY.
GAS
2"
3"
11"
6"
1/4"
1 1/2" R
1 1/2" R
3"
3"
3/8"
1/4"
COMBUSTION CHAMBER 4" COOLING FINS
7"
1/2"
SUPPORT
NICKEL STEEL NOZZLE
GAS.
LOXY.
3/4"
3 3/4"
NOZZLE COOLING FINS
1/2"
BOTTOM VIEW.
©1944. C.P. LENT
SINGLE AND MULTIPLE AIR COOLED ROCKET MOTOR
DRAWN BY: CONSTANTIN PAUL LENT
MATERIAL: ALUMINUM CASTING—NICKEL STEEL NOZZLES
SCALE: NO SCALE
PLATE NO. 0010

FIG. 52

Two types of liquid fuel rocket motors. The one on the left is a single nozzle air-cooled motor and the one at the right is a multiple nozzle motor. Both motors have the same overall dimensions and differentiate only in the number of nozzles. In constructing any of these motors follow dimensions as close as possible.

Plastics like Bakelite have this advantage over metals in making tanks: being in fact thermal and electrical insulators, they can reduce considerably the amount of losses sustained in filling them with liquid oxygen or other fuels with low boiling points. Up to the present time, where the use of metals for tanks has been exclusive, this factor has been a source of great annoyance and danger

The subject of plastics has scarcely been scratched. Their properties at extremely low temperatures are not fully known.

Manufacturing them to suitable forms is usually easier than with most other substances.

Taking all in consideration, Molybdenum copper or Aluminum for the motor and Duralimin or Ber-Copper for the tanks would be our best choice at the present time.

There are three methods of calculating that efficiency of the rocket which depends only on the ratio of the velocity of the rocket to the velocity of the jet relative to the rocket.

The first method uses a value for the output which satisfies the definition of work—force times distance, but considers the input to vary. This is incorrect for the assumption of a constant jet velocity and throat area as under these conditions the input per second is constant. The second method uses a constant input and a more definite output—the difference between the input and the absolute energy left in the trailing exhaust gases. By dividing the output of the first method by the input of the second, the writer obtains a third method for comparison.

The velocity-ratio efficiency by this last method is a simple straight-line formula; it is the tangent to the efficiency curves of the preceding methods. The efficiency calculated by this method is simply twice the velocity-ratio. However, it must be rejected at once because for values greater than one-half the efficiency would be over 100%, or inconsistent with the law of conservation of energy. Its value is in showing up the effect of the decreasing mass of the rocket and in answering the question: Is the kinetic energy gained by the unconsumed fuels to be considered as available for propulsion or not?

It is shown that Equations 1 and 3 include this energy; Equation 2 does not. When it is considered that the slightest internal force will separate two bodies that happen to be travelling together, no matter what the speed, and that the only effect on the forward body is this force—it seems clear that the absolute energy of the lost mass is of no further use. Therefore, Equation 2 is concluded to be the correct form for calculating the velocity-ratio efficiency.

From the definition of work, "force times the distance through which it acts", the useful work done per second can be considered as the jet reaction times the velocity of the rocket. If the only loss is the kinetic energy left in the gases of the jet, and this is supplied as additional input, the velocity-ratio efficiency is:

$$E = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output plus Losses}}$$

$$Fv$$

$$Fv + \frac{m(c-v)^2}{2}$$

$$mcv + \frac{m(c-v)^2}{2}$$

$$2cv$$

$$c^2 + v^2$$

where

E = instantaneous velocity-ratio efficiency percent

F = jet reaction, lbs., (equals mc)

v = velocity of rocket, ft. per sec.

m = mass of gases flowing through nozzle per sec. (slugs per sec.)

c = velocity of jet, ft. per sec. (constant)

The substitution of mc for F follows from the funamental relation, the jet reaction is the product of the mass flow per second times the jet velocity.

Dividing both numerator and denominator of the last by c^2, and substituting r, the velocity ratio, for v/c, the simplified formula becomes

$$\frac{2r}{1 + r^2} \quad \ldots . \; (4)$$

This is the instantaneous efficiency at any particular value of the velocity-ratio, r. Although it may reach 100% when r =, 1, it must first pass through the intermediate velocity-ratios with their corresponding low efficiencies. Therefore, more important than the instantaneous

TABLE II

Fuel Tank Metals

Metal	Sp. Gr.	Ten. Str. lbs/in^2	Sp. Ten. strength	Therm. Cond.	Mech. Properties at —186°C
Dow metal	1.8	40,000	22,200	20	Not known
Duralimin	2.8	65,000	23,200	30	T. S. improved
Cro-Mo-Steel	7.8	175,000	22,100	5	Becomes brittle
Ber.-Copper	8.2	193,000	23,500	40	T. S. probably imp.

Other Possibilities

Metal	Sp. Gr.	Ten. Str. lbs/in^2	Therm. Cond.	Mechanical Properties at low temperatures
Lead	11.34	1,500	10	TS becomes greately increased
Lithium	.53		20	May behave like lead

TABLE III

Refractories

	Crushing Strength			
	1000°C	1500°C	M.P.°C	Density
Alumina	9,800 lbs/in^2	200 lbs/in^2	2050	2.6
Carborundum	7,500 lbs/in^2	1,000 lbs/in^2	2200	2.5
Magnesia	3,000 lbs/in^2	450 lbs/in^2	2800	2.5
Quartz	10,000 lbs/in^2	1,500 lbs/in^2	1700	1.8
Zirconna	5,000 lbs/in^2	150 lbs/in^2	2950	4.0
Graphite	T. S. equals	2,500 lbs/in^2	3500	2.2 - 2.3

TABLE IV

Plastics

	Tensile Strength	Density	M.P.°C
Pyroxylin (Celluloid)	8,500 lbs/in^2	1.35	85
Phenol Resins (Bakelite)	25,000 lbs/in^2	1.32	200

efficiency for determining the performance in a given interval is the average efficiency of the interval. This can be expressed for any curve as the mean ordinate, M.O., or the area under the curve divided by its length along the horizontal axis.

The area under the curve from $r = 0$ to any value of r is found first, by integrating a differential element of area between the limits zero and r.

$$= \int_0^r dA = \int_0^r E\,dr$$

$$\log_e(1+r^2)$$

The mean ordinate is

$$M.O. = \frac{\log_e(1+r^2)}{r} \quad . \text{ (1a)}$$

Equation 1a. What is the significance of Since there is a maximum average efficiency it is important to know at just what velocity-ratio this occurs so that the rocket can be designed to reach the final velocity-ratio at the end of the combustion.

Equating the first derivative of equation 1a to zero for a maximum,

$$\log_e(1 + r^2)$$

This last equation is a bit difficult to solve, but by integrating graphically a first approximation can be obtained. Successive trials result in the solution $r = 1.98$. This value of r substituted in equation 1a gives for a rocket without initial velocity the maximum average velocity-ratio efficiency.

max. E aver. = 80.5%

The total energy in the jet available per second is half the mass-flow per second times the velocity squared. Considering this as the total input per second and again the residual energy in the jet as

$$= \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output + Losses}} = \quad Fv + \cdot$$

$$\frac{2cv}{\quad}$$

the only loss, the velocity-ratio efficiency is

replacing v/c by r,

$$E = 25 - r^2 \qquad \text{(2a)}$$

For 100% efficiency in this case,

$$r = 1, \text{ as before}$$

To get the mean ordinate,

$$A = \int_0^r (2r - r^2)\,dr = r^2 - \frac{r^3}{3}$$

$$\text{and} \quad M.\,O. = r -$$

(3a)

For maximum M. O.,

$$1 - \frac{2r}{3} \quad 0, \text{ or } r = 1.5$$

and max. E. aver. = 75%.

Using the input of the previous method and the output of the first method, the efficiency is

$$E = 2r \qquad \text{(4a)}$$

$$\text{and } M.\ O. = r \qquad \text{(5a)}$$

Since Equation 4a can be valid only for values of r equal to or less than one-half, giving over 100% efficiency for greater values, it must be rejected. It is clear that the equation contains some source of energy not in agreement with the fundamental laws of physics.

By grouping Equations, 1a, 2a and 3a, clue to their discrepancy is immediately apparent. The term 2r occurs in all three. The term r^2 subtracted from the 2r of Equation 3a gives Equation 2a; and the same term plus one divided into 2r gives Equation 1a What is the significance of this term?

A simple transformation, multiplying its equivalent, $(v/c)^2$ through by m/2 shows it to be the ratio of the kinetic energy of the lost mass to the kinetic energy of the jet. Therefore, in Method 3 the output Fv, must have contained this energy, thus canceling the r^2 of Equation 2a; and in Method 1, in addition to this error, the additional error of adding the same lost energy to the jet energy placed another r^2 in the denominator. The double error can be easily demonstrated by multiplying

$\frac{2cv}{c^2+v^2}$ through by m. The result is

$$E = \quad \frac{mcv}{\frac{mc^2}{2}}$$

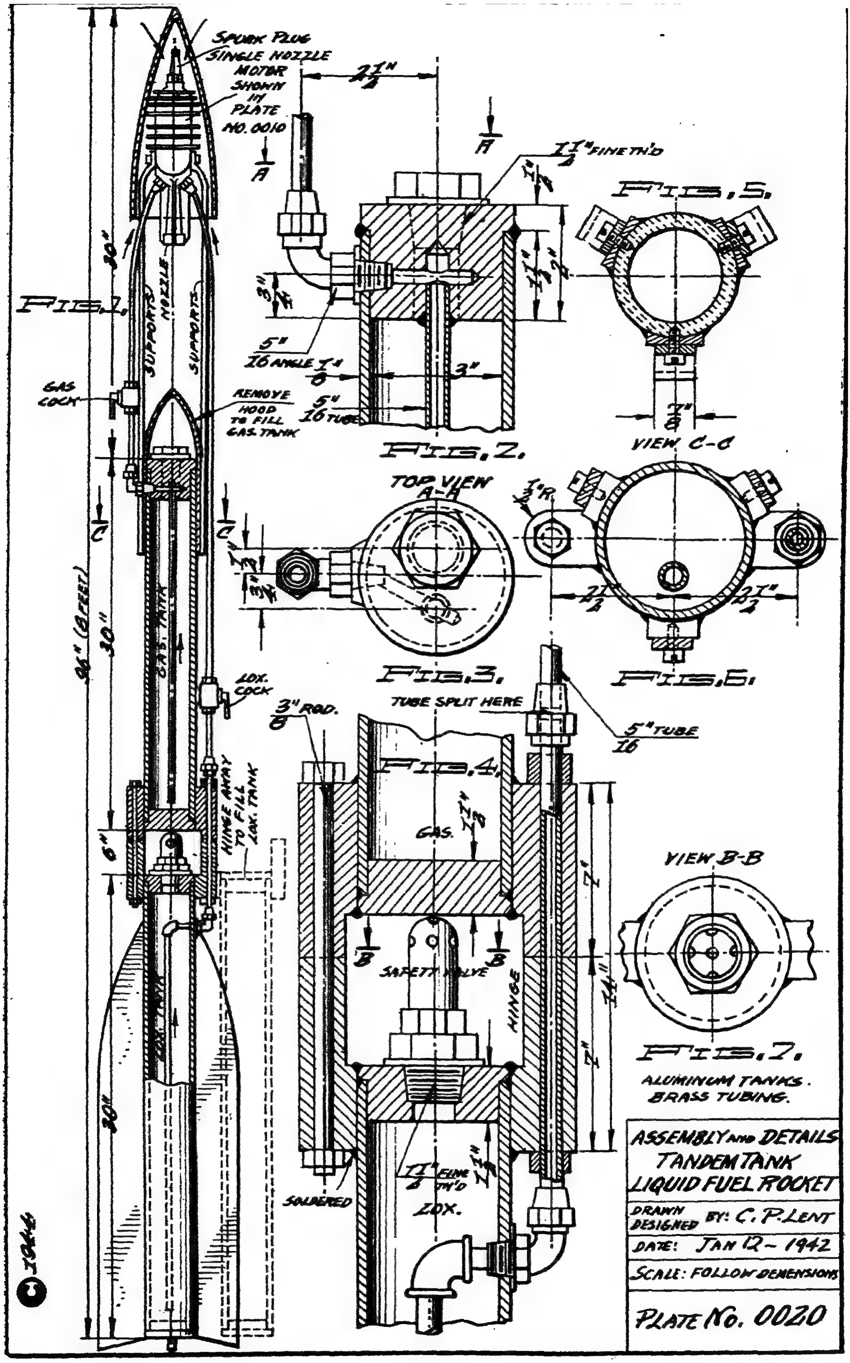

SPARK PLUG
SINGLE NOZZLE MOTOR SHOWN IN PLATE NO. 0010
2 1/4"
A
A
1 1/4" FINE TH'D
1/4"
1 1/4"
2"
FIG. 5.
FIG. 1.
30"
SUPPORTS
NOZZLE
SUPPORTS
3/4"
5/16" ANGLE 1/8"
3"
5/16" TUBE
GAS COCK
REMOVE HOOD TO FILL GAS. TANK
FIG. 2.
7/8"
VIEW C-C
TOP VIEW A-A
1/2" R.
C
C
1 1/4"
3/4"
2 1/4"
2 1/4"
GAS. TANK
30"
96" (8 FEET)
LOX. COCK
FIG. 3.
FIG. 6.
TUBE SPLIT HERE
3/8" ROD.
5/16" TUBE
FIG. 4.
HINGE AWAY TO FILL LOX. TANK
6"
GAS.
1 1/8"
7"
VIEW B-B
B
B
SAFETY VALVE
HINGE
14"
7"
FIG. 7.
ALUMINUM TANKS.
BRASS TUBING.
LOX. TANK
30"
1 1/4" FINE TH'D
1 1/2"
SOLDERED
LOX.
ASSEMBLY AND DETAILS
TANDEM TANK
LIQUID FUEL ROCKET
DRAWN DESIGNED BY: C. P. LENT
DATE: JAN 12 - 1942
SCALE: FOLLOW DEMENSIONS
PLATE NO. 0020

FIG. 53

A design of a tandem cylinder rocket. Total length of the rocket is approximately 96 feet with each of the fuel cylinders being 30 inches long and 3 inches inside diameter. The upper cylinder holds the gasoline while lower cylinder is for the oxygen. Note that the oxygen cylinder can be hung sideways to facilitate filling. Fig. 1 is the general assembly of the rocket. Fig. 2 is a section through the upper portion of the gasoline cylinder. Fig. 3 is the top view of the gasoline cylinder. Fig. 4 is a cross-section through the hinge portion of the oxygen cylinder. Fig. 5, is a cross-section through the rocket supports. Fig. 6 is a section on the line C-C of Fig. 1. Fig. 7 is a top view on the line B-B of Fig. 4.

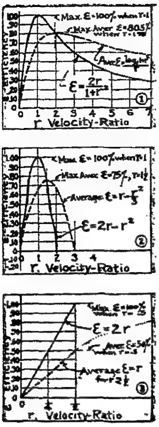


FIG. 54

Perhaps the most striking illustration of the loss occurs when the velocity-ratio becomes greater than 2 In truth the graph shows that the instantaneous velocity-ratio efficiency is then negative. This is because the rocket is losing fuel having a higher kinetic energy than can be given to the remaining mass by further acceleration. The velocity continues to increase at the expense of the total kinetic energy. Since there is no foundation for assuming that this energy is recoverable as additional input, and since Method 2 rejects it, Equation 2a is the only satisfactory solution for the instantaneous velocity-ratio efficiency.

For the rocket motors and giving an average reaction of 40 lbs. for ten seconds, the average acceleration of a 15 lb. rocket (inclusive of 3 lbs. of fuel at the start) would be 2g. Therefore, its final velocity in a vacuum would be 2gt or 640 ft. per second. Since the jet velocity is

$$c = \frac{F}{m} = \frac{40 \times 32}{.3}$$

$$= 4300 \text{ ft. per}$$

second, the final velocity-ratio is .15, giving final efficiencies from the three methods of .293, .298, and .300 respectively.

The average efficiencies for the ten second interval would be .149, .143, and .150 respectively.

It must be emphasized that this average efficiency of about 15% is only one of the several separate efficiencies which together make up the over-all or absolute efficiency of the rocket. Imperfect combustion in the rocket motor prevents the maximum temperature from being reached. In addition, dissociation at these high temperatures keeps the chemical reaction from being completed.

The next loss is at the nozzle. The limiting velocity of flow is the speed of sound at the temperature of the gases—unless the nozzle is designed for the theoretical expansion ratio. However, this is impractical at present, and in addition our experiments indicate for some unknown reason that short nozzles give higher and longer reactions than the more theoretical longer nozzles.

Then the actual kinetic energy of the jet (whatever its efficiency) is considered to be the input for Methods 2 and 3 in deriving the velocity-ratio efficiency.

The maximum velocity and altitude depend on the ratio of fuel weight to rocket dead weight (construction plus meteorological instruments). The jet reaction minus the dead weight is evidently the maximum weight of fuel that could be lifted at all. Any more fuel would simply burn away, uselessly, until the total weight reduced to less than the value of the reaction. Increasing the jet reaction and decreasing the dead weight to a maximum are the two practical problems involved.

Finally there is the resistance of the air to be sonsidered. Calculations taking this and all other variables into account by the method of numerical integration used in ballistics show that this loss may be as great as 50%.

For comparison with the velocity-ratio efficiency the probably absolute efficiency corresponding to the rocket data used in the example should prove interesting.

For a vertical shot, the flight under power would be

$$S_1 = at^2 \qquad 3200 \text{ ft. (in a vacuum)}$$

As a projectile,

$$S_2 = \frac{v^2}{2g} = - \quad -S_1 = 6400 \text{ ft.}$$

(in a vacuum)

Total = 9600 ft. (in a vacuum)

Assuming 50% loss due to air resistance or 50% "air resistance efficiency" the net altitude in the air would be 4800 ft.

The useful work is the final weight of the rocket times its altitude, 12 x 4800 = 57,600 ft. lbs. The total (bomb-calorimeter) energy in 3 lbs. of gasoline-liquid oxygen fuel mixed in the correct proportion is 12,000 B. TU. or 9,350,000 ft. lbs.

Therefore the absolute efficiency is .006 or 6/10 of 1%, for this case.

In general, there are two types of rockets, namely powder rockets and liquid fuel rockets. The fuel of a powder rocket consists of some form of explosive suitably packed into the firing chamber. The most commonly used mixture is an explosive of the nitrate type, such as ordinary gunpowder, or some modification thereof. Explosives of the chlorate type have also been used, sometimes with disastrous results. Mixtures containing potassium chlorate are now considered too unsafe to be of value. A number of German experimenters have been killed by an explosion of chlorate powder.

Of fuels suitable for use in liquid fuel rockets we can consider both liquefied gases and substances liquid at ordinary temperatures. These include alcohols, liquid hydrogen, various hydrocarbons, and certain other organic compounds. It is an interesting fact that only two chemical elements are of any importance as fuel constituents, namely, carbon and hydrogen. As a general rule, hydrocarbons comprise the most important group of liquid fuels. Other organic compounds contain inert ingredients from the point of view of combustion, and therefore have a lower calorific power. Fuels are commonly rated on the basis of B. T. U. per pound, this being a measure of the energy content of the fuel. In rocket work it is more convenient to compare fuels on a somewhat different basis.

Since a rocket must carry not only its fuel, but also the oxygen necessary for the combustion, as well as pressure tanks, which comprise a large part of the total weight, the calorific power of fuels based on total volume becomes just as important, as that based on total weight. To illustrate this, two tables have been compiled. Table A gives calorific powers of fuels based on weight, while Table B gives heats of combustion based on the unit volume of one pint. The theoretically necessary quantity of oxygen has been included in evaluating the total amount of active ingredients in each case.

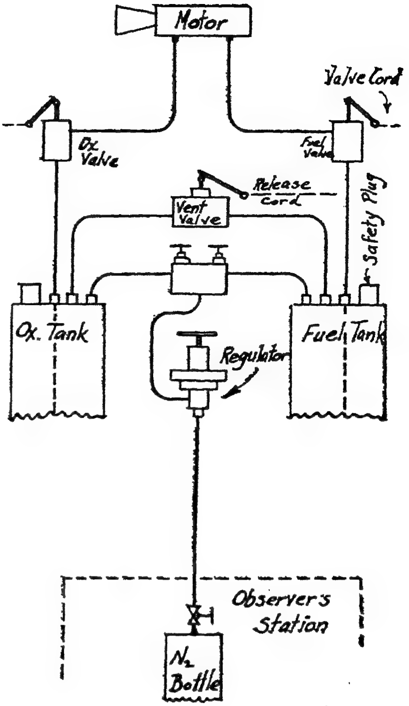


FIG. 55

Piping schema of a proving stand. Note the oxygen and gasoline cylinders, also the nitrogen bottle at observer's station.

Gasoline and kerosene are not definite chemical compounds, but rather mixtures of various hydrocarbons, and for that reason they have not been included in the tables as such. For practical purposes it is sufficiently accurate to consider gasoline as equivalent to either heptane or hexane, depending on the specific gravity of the sample, while dodecane is fairly representative of average kerosene.

It is interesting to note that there is not so much difference between liquid fuels as might be expected. Hydrogen is the best fuel on the weight basis, but this fact is only due to the phenomenally low specific gravity of liquid hydrogen. Liquid hydrogen is not made commercially. It is much more difficult to handle that liquid oxygen. Liquid acetylene shows up very favorably, but due to its unstable nature, is a rather dangerous substance, decomposing with great violence under some conditions. Benzol appears to be the best available fuel, but its relatively high freezing point of —42°F. makes it difficult to keep feed lines open when in proximity to liquid oxygen.

TABLE A

Heats of Combustion of Various Fuels by Weight

Substance	B.T.U per lb	Lbs. Ox. Required	Lbs total weight	B.T.U per lb. of total weight
Hydrogen	51900	8.00	9.00	5760
Acetylene	20700	3.08	4.08	5060
Ethylene	20000	3.43	4.43	4520
Benzol	17300	3.08	4.08	4330
Methane	21400	4.00	5.00	4280
Ethane	20200	3.73	4.73	4260
Pentane	19300	3.56	4.56	4240
Hexane	19200	3.54	4.54	4230
Heptane	19100	3.52	4.52	4220
Dodecane	18700	3.48	4.48	4170
Ethyl Alc.	12100	2.44	3.44	3520
Methyl Alc.	9100	2.00	3.00	3030
Smokeless Powder	1870	0.00	1.00	1870
Black Powder	1000	0.00	1.00	1000

TABLE B

Heats of Combustion of Various Fuels by Volume

Substance	Sp. grav. water – 1	Pints required	B.T.U. per pint	Ox. pint	B.T.U. total	per Boiling Pt F°
Benzol		.879	15860	2.36	4730	—176
Acetylene		.520	11200	1.39	4700	—121
Dodecane		.770	15000	2.33	4510	—417
Heptane		.690	13750	2.11	4420	—210
Hexane		.660	13200	2.03	4360	—156
Pentane		.634	12750	1.96	4310	— 99
Methane		.466	10400	1.62	3970	—243
Ethane		.466	9820	1.51	3910	—123
Ethylene		.411	8560	1.22	3860	—152
Eth. Alc.		.789	9960	1.68	3740	—172
Meth. Alc.		800	7600	1.39	3180	—151
Hydrogen		.071	3850	.49	2580	—423
Oxygen		1.150				—297

It should also be noted that in order to realize the greatest amount of the available potential energy of the fuel, the shape of the combustion chamber, and the arrangement of the fuel inlets should be adapted to the particular fuel being used. The flame characteristics and speeds of combustion differ with various fuels. Unfortunately sufficient experimental data is lacking on this important subject, at present, to enable one to design the most efficient rocket motors. Only a small percentage of the heat energy is utilized, but as the development work goes on, greater efficiency will be attained.

In proving stand tests, at which the writer was present, three different fuels were tried, namely Pentance, Heptane, and Ethyl Alcohol. The best results were obtained with Ethyl Alcohol. This, in spite of the lower calorific power of Alcohol, as compared to either Pentane or Heptane, is believed to be due to the fact that the rocket motor, because of its shape, was able to utilize the fuel with greater efficiency in the case of Alcohol. Furthermore, Alcohol contains less carbon than the two other fuels tried.

In general, it appears that a large percentage of carbon in a fuel will decrease the speed of combustion and make for a longer flame, while a larger percentage of hydrogen produces the opposite effect.

The ratio of the heat energy of fuel to the weight of rocket is of interest. In a "2 pound" powder rocket that was examined by the writer this was found to contain a driving charge of 23 gm. of black powder, with a total weight of 242 gm. which is equivalent to 95 B.T.U. per pound overall.

In a rocket weighing 20 pounds and carrying 5 pints of gasoline, this corresponds to an available energy content of 1320 B.T.U. per pound overall, which is nearly 14 times that of the powder rocket.

Having discussed up to now matters pertaining to nozzle design combustion chamber, and tank materials, efficiency and fuels we find that probably the most important problem of rocket research to the practical experimenter is the metal problem. At some test that the writer was present the melting of the nichrome nozzles made it pretty definite that the combustion temperature of the fuels used was well over 3000 degrees Fahr. To get around this difficulty there were investigated four methods: One use of a metal like molybdenum or tungsten whose melting point exceeds that of the flame temperature; cooling the motor by circulating the fuels and the liquid-Oxygen through its walls; use of a refractory such as carborundum for a lining; and injection of water to create a layer of insulating steam on the inner walls of the chamber and nozzle.

This illustrates the great advantage of liquid fuel over powder rockets. Liquid fuel rockets have potentialities which, for any distance flights, leave the powder rockets out of consideration.

A cross-section through a rocket motor in which there is shown the manner in which fuel is circulated through the walls of the combustion chamber (regenerative principle) see Figures 14, 39 and 47.

Other practical problems for the experimenter to work on I found to be; proper construction of the tanks and connections to withstand the high pressures while at the same time subjected to sharp temperature changes; methods of supplying a constant feed pressure as for example by the use of a small high pressure nitrogen tank with a reducing valve; and, in general, dependable apparatus for the continuous measurement of: the fuel and liquid-oxygen flow, the jet reaction, the tank and combustion chamber pressures, the exact flame temperature, the jet velocity, and the chemical analysis of the jet gases.

For the past thousand years, the powder type of rocket has been manufactured by rule-of-thumb methods, handed down in certain families from generation to generation. A well-known fireworks manufacturer, upon seeing thrust curves and calculations showing that his best powder rockets developed only 2½% thermal efficiency said it was the first time in the fifty years he had been selling rockets that he had seen any such calculations. The explanation of this situation is no doubt that the limitations set by the use of gunpowder prevented the rocket's

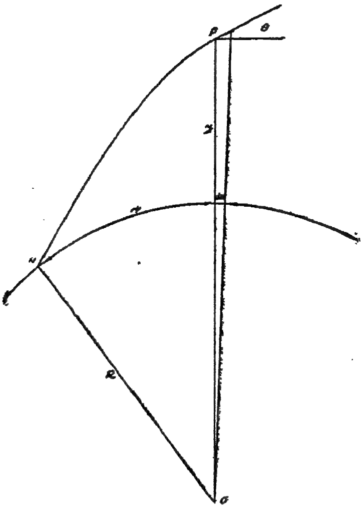


FIG. 57

scientific development for any use other than the fourth of July type of firework it has been for centuries.

The application of liquid-oxygen has changed the situation completely. Whereas combustion in the gunpowder rocket is uncertain and generally uncontrollable, combustion in the liquid fuel rocket can be controlled quite easily by valves. The liquids in themselves are not explosive, so that the rocket reaction motor is quite analogous to the ordinary internal combustion engine in this respect. A rational design of a liquid fuel rocket is consequently practical. The duplication of high jet reactions in test after test for like conditions clearly demonstrated this. By plotting all values of the jet reactions corresponding to various combustion chamber pressures, as shown in the typical motor performance curves, the following fundamental relationship for the jet reaction was obtained:

$$1.55\ A\ Pc \qquad (1)$$

where R is the jet reaction in lbs., A is the area of the nozzle in sq. in., and Pc is the chamber pressure in lbs. per sq. in. gage. For a ½ inch diameter nozzle (area .20 sq. in.) and 300 lbs. per sq. in. chamber pressure, this equation shows that 93 lbs. will be the probable reaction.

A second empirical formula resulted when the average weight of liquids flowing into the motor during each run was plotted against the average combustion chamber pressure of the run.

$$.0135\ A\ Pc \qquad (2)$$

where w is the jet flow in lbs. per sec. Thus the flow of the liquids for the example can be calculated from this formula to be .81 lbs. per sec.

A third empirical formula was similarly found to show the drop in pressure between the feed tanks and the motor. This of course depends upon the length and size of the connections: for the proving stand setup this relation was:

$$Pc \quad .75\ Pf \qquad (3)$$

where Pf is the average of the two tank pressures, lbs. per sq. in. Therefore, for similar conditions, the feed pressure required to maintain 300 lbs. per sq. in. chamber pressure will be 400 lbs. per sq. in. in the tanks.

Combining Equations 1 and 2 gives a convenient relation between the jet reaction and the jet flow.

$$115w \qquad (4)$$

Upon examination these formulas are seen to be based on an average jet velocity of 3700 ft. per sec., and an average thermal efficiency of about 7%. It is probable that the jet velocity was limited since the incomplete expansion in the nozzle made it a little better than a simple orifice, where the maximum exit velocity is that of sound at the temperature and other conditions of the hot gases. Where there is constant feed pressure this velocity should increase since the nozzle expansion ratio will then be designed for a definite chamber pressure.

The next point to be considered is the fundamental equations for use in the calculation of rocket trajectories. The formulas given assume a stationary earth with no wind. The nomenclature and methods used in exterior ballistics are applied; especially as regards air resistance. The formulas are general in their application. A discussion of the factors involved will follow.

A rocket may or may not have an initial velocity. The rocket will receive an acceleration from its motor during the first part of its flight. Air resistance acts throughout the entire trajectory

Consider the rocket at any point P, t seconds after leaving the earth's surface at N, then from Figure 57

$$x' = \frac{R}{R + y} v \cos O \text{ and} \qquad (1)$$

$$y = v \sin O \qquad (2)$$

where

x = the range to P measured along the curved surface of the earth.

y = the height of P above the surface of the earth

v = the velocity.

O = the inclination of the trajectory to the horizontal.

R = the radius of the earth.

and primes denote the derivatives with respect to time. These formulas are independent of any retardation or acceleration effects present.

The relations for retardation and acceleration effects are:

$$\frac{d(v \cos O)}{dt} = E v \cos O + f \cos O \qquad (3)$$

$$\frac{d(v \sin O)}{dt} = E v \sin O - g + f \sin O \qquad (4)$$

Eliminating cos O from 1 and three there results:

$$x'' = -Ex' - \frac{xy}{R + y} + f \frac{y}{v} \qquad (5)$$

Likewise from 2 and 4;

$$y'' = -Ey' - g + f \frac{y'}{v} \qquad (6)$$

The intensity of gravity at autitude y is expressed in terms of gravity at altitude zero by

$$g = g^o \frac{R^2}{(R + y)^2} \qquad (7)$$

Expressions for the velocity and inclination are:

$$v^2 = (y')^2 + (x')^2 \frac{(R + y)^2}{v} \qquad (8)$$

$$\tan O = \frac{y R}{x' (R + y)} \qquad (9)$$

Ev is the retardation of the rocket due to air resistance. E. is a function of the rocket's shape and weight, its velocity and the density of the air

$$E = \frac{GH}{C} \qquad (10)$$

G is a function of the velocity alone. H is the ratio of air density at altitude y to the density at elevation zero.

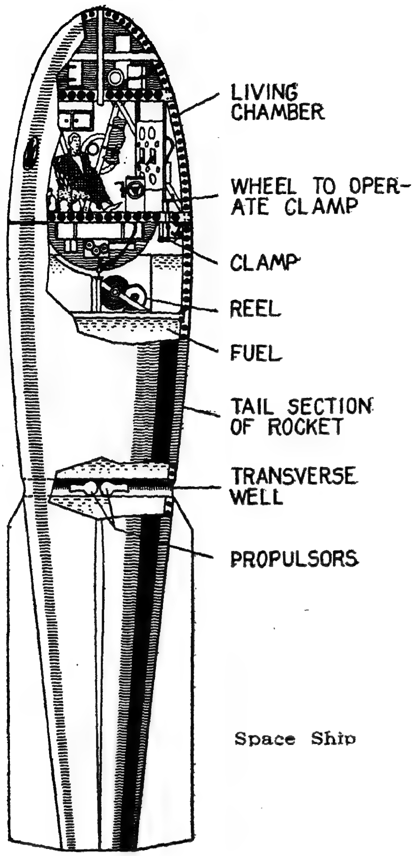
$$H = a(10)^{-hy} \qquad (11)$$

Up to an altitude of 10,000 meters, a = 1 and h = 0.000045. Above 10,000 meters, a = 1.5849 and b = 0.000065. (These constants are for y in meters.) C is the ballistic coefficient of exterior ballistics.

$$C = \frac{w}{id^2} \qquad (12)$$

where

w is the weight of the rocket in pounds, i is a coefficient depending on the rocket's



Space Ship

shape and d is the maximum diameter of the rocket in inches.

Rockets using reaction gas jets for their propulsion will be considered here. Let F be the thrust delivered to the rocket and z the weight of gas flowing per second after any time t. Considering the flow as in the critical range then:

$$z = j\frac{A\,R}{R \div y}\sqrt{\frac{P}{V}} \qquad (13)$$

and,

$$F = k\,A\,P\sqrt{1-\left\{\frac{p}{p}\right\}^{\frac{n-1}{n}}} \qquad (14)$$

w is given by;

$$w = w_0 - \int_0^t z\,dt \quad \text{where} \qquad (15)$$

P = the absolute chamber pressure.
V = the chamber specific volume.

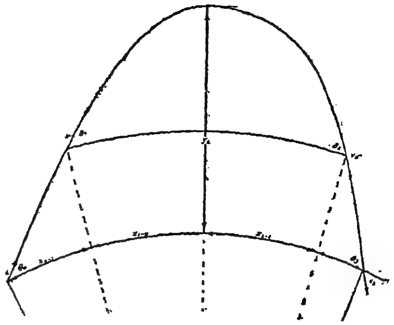


FIG. 58

p = the atmospheric pressure.
w_o = the initial weight of the rocket.
A = the area of the nozzles.
n = a gas constant.
and j and k are constants depending on the efficiency of the system.

Since critical flow only is considered, P and V become functions of the time alone. Each rocket motor would be rated by plotting P and V against time for a particular fuel loading. The acceleration is given by,

$$f = \frac{F\,g}{w} \qquad (16)$$

Formulas (13) and (14) are theoretical and need not fit the actual conditions such that j and k will be constant throughout the range of P.

All of the factors involved in equations (5) and (6) are now evaluated as functions of y, v and the characteristics of the particular rocket at hand. Equations (5), (6), (7), (8), and (9) may now be used to calculate the entire trajectory. It is logical this be accomplished by numerical integration methods.

The powered portion of a rocket's trajectory will be on the ascending branch and most logically under the 10,000 meter level. Call this region Zone I. Zone II will refer to that region above 10,000 meters.

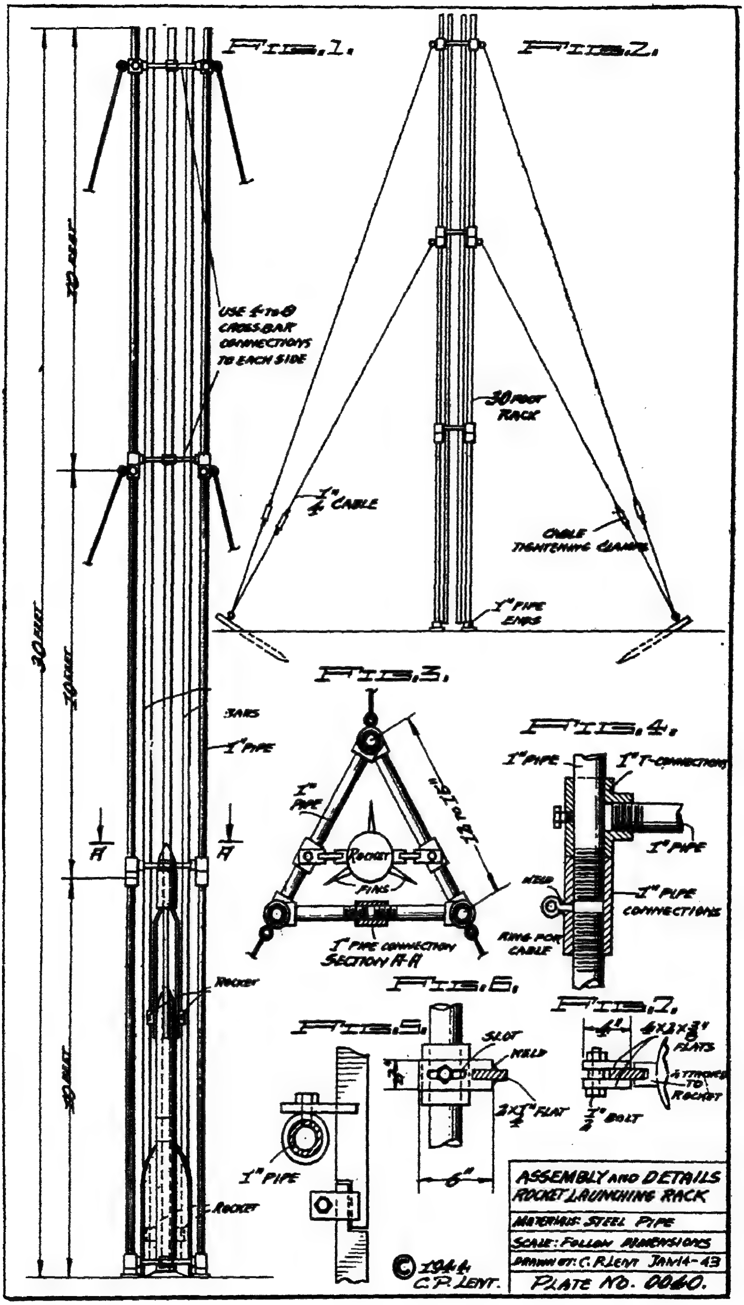


FIG. 1.
FIG. 2.
FIG. 3.
FIG. 4.
FIG. 5.
FIG. 6.
FIG. 7.
USE 4 TO 8 CROSS BAR CONNECTIONS TO EACH SIDE
10 FEET
30 FEET
10 FEET
10 FEET
BARS
1" PIPE
A
A
ROCKET
ROCKET
30 FOOT RACK
1/4" CABLE
CABLE TIGHTENING CLAMPS
1" PIPE ENDS
1" PIPE
ROCKET
FINS
12 TO 16"
1" PIPE CONNECTION
SECTION A-A
1" PIPE
1" T-CONNECTIONS
1" PIPE
WELD
1" PIPE CONNECTIONS
RING FOR CABLE
SLOT
WELD
2X1/4" FLAT
6"
1" PIPE
4"
4X2X3/8" FLATS
ATTACHED TO ROCKET
1/2" BOLT
ASSEMBLY AND DETAILS ROCKET LAUNCHING RACK
MATERIALS: STEEL PIPE
SCALE: FOLLOW DIMENSIONS
DRAWN BY: C. R. LENT JAN 14-43
PLATE NO. 0040.
© 1944 C. P. LENT.

FIG. 59

The launching rack shown above is built pletely of one-inch piping. Note that the three upright supports of 30 feet are made in three 10 foot sections each and are cojoined with one-inch pipe connections. The rocket is slidadly held upon a pair of guide bars. Fig. 1 shows the assembly of the launching rack with the rocket at the bottom. Fig. 2 is showing the manner in which the rack is held upright by means of cables. Fig. 3 is a section taken on the line A-A of Fig. 1. Fig. 4, 5 and 6 are details of the guide bars for the rocket.

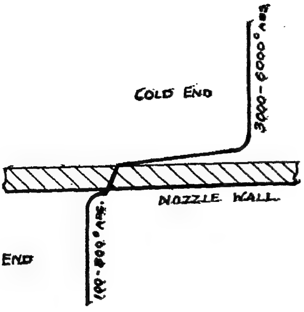


FIG. 60

It may not be stated that the preceding suggested methods are final. Progress is continually being made in design and computation methods.

Sometime ago an importation equation of rockety was developed At first much of its significance was probably lost to many, because of its cumbersome form. This ad simplified formula and relate it to old formulas and test data.

The formula was

$$R = \frac{2 A P_1 \sqrt{1 - \left\{ \frac{P_2}{P_1} \right\}^{\frac{s-1}{s}}}}{\sqrt{\left\{ \frac{2}{s+1} \right\}^{\frac{2}{s-1}} \frac{s^2}{s^2 - 1}}}$$

This can be written by $R = Kr\ A\ P_1$, where Kr is a function of the pressure ratio, P_1 and of s. But s varies consider-

P2

ably with temperature and with different gases; and in the rocket combustion and expansion processes several gases are involved, over a wide temperature range. What value of s is to be used?

The most probable values are between 1.2 and 1.3, extending somewhat on each side. For CO_2 at 3500 - 5000°F, is 1.16, while at 70°F it is 1.28. Superheated steam runs about 1.30. CO and C_2 which are present if the combustion is incomplete, vary between 1.25 and 1.4, depending on the temperature.

Fortunately, upon further investigation, the dilemma disappears; no assumption need be made, and no laborious procedure need be followed. In plotting the values of Kr against $P2/P_1$, for several values of s, the lines are to be found to nearly coincide. The value of Kr is nearly independent of the value of s. The accuracy of the curve shown is 1% down to .06, and within 2% down to .25. At 0.0 the range is from 1.8 '(s = 1.4) to 2.24 (s = 1.2).

Low pressure, inefficient rockets have values of the pressure ratio between .2 and .3 but the tests.

The attempts to measure P_2, but have proved unsatisfactory although one can experimentally determine its approximate value. The values of Kr can be computed from the instantaneous values of P_1 and F

At some test the author was fortunate to be present the value of Kr was usually 1.3 (it jumped to 1.7 sometimes) for the short nozzles. The value is between .7 and 1.1 for the long nozzles.

At some other tests, the value of Kr was consistently between 1.3 and 1.6, with a number of values at about 1.5. This corresponds to a pressure ration range of from .015 to .085, with the majority at .025.

Supposedly, the absolute lower limit of these motors discharging into the atmosphere would be

15 lb/sq. in.

190 lb/sq. in.

or 0.08. (190 is above average chamber pressure). There is therefore not yet close agreement between theory and experiment, but when the experiments are complete enough to have consistent results, perhaps the theory can be modified to fit.

In the meantime, experimenters have achieved one important result. The old, and very simple, formula that R= A P_1 is found to be true when expressed as $R = Kr\ A\ P_1$, where Kr has been experimentally determined as about 1.5.

As for actual performances of rocket motors and their utilization, it must be said that as practical flight technique demands for certain special purposes an apparatus other than a propellor mechanism for the production of very high motive power for a short time only; for example, modern long-distance transport planes, due to their aero-dynamic refinement, fly with such relatively weak motors that their take-off with slight reserve power is very long and troublesome; rocket motor or hot air jet propulsion methods have been found at present very useful to overcome these disadvantages. Similar starting difficulties have for a long time existed with powerfully-motored planes taking off from the water. In like fashion the velocity of ascent of pursuit machines with any given motor is very limited, nor can they practically climb high enough because a sufficiently powerful motor for ascent would be unnecessarily heavy for the task of flight and landing. Again, for certain flying performances (for example speed record flights) high powers of impulse are especially necessary. In this instance the high motive power is only usable through short intervals of time. In all these examples, the few seconds at the start or the few minutes necessary for rapid ascent or for speed records make demands which correspond fundamentally to those fulfilled by rocket motors. Their other far-reaching realms of application and their further development is known.

Through the rapid expulsion of fuel mass m with effective velocity c opposite to the direction of flight during a short interval of time t, the rocket motor must exert on the flying mechanism a high thrust, P = mc. Therefore the greater c with a given thrust and time of operation, the smaller need be the total fuel carried, mt; similarly with a given fuel and a given thrust, the greater is the duration of the thrust. The primary demand on the rocket motor is therefore the greatest possible effective jet velocity. The introduction of rockets into flight technique has already become a serious question now than an exhaust velocity of c = 3000 meters per second can be reached.

At present there is a way open for the attainment of high jet velocities. Combustion of fuel mixtures (fuel-oxygen) converts the heating value E in calories per kilogram of mixture into gases of high heat content.

$$= \int c_p \, dT = n_0' E$$

and accordingly a high temperature T is developed in a combustion chamber capable of withstanding it; the gases of combustion then transform their heat into the energy of the exhaust jet according to the energy of the transpiration of gases.

$$c^2/2g \quad n_d \, J_0/A$$

is the specific heat in calories per kg of the exhaust gas at constant pressure, g in meters per second^2 is the acceleration of gravity, and A in calories per kg is the mechanical equivalent of heat. Neither of the energy changes follows completely according to the determined efficiency—the combustion with the chamber efficiency nd = Jo, and the exhaust with the nozzle efficiency nd = $c^2/2g$:Jo/A. The entire reaction occurs continuously and under a constant high pressure.

The chamber efficiency no was investigated sometime ago in a great number of model tests with oil-oxygen motors. The completeness of the change of energy E into Jo and with it the chamber efficiency, is determined principally by the completeness of the combustion within the chamber. Other losses are unimportant in comparison with this—especially the loss of heat through the walls of the chamber when the propellants themselves are applied as coolants and arrive preheated to the combustion chamber.

The completeness of combustion depends on the thoroughness with which the propellants are mixed and the length of time they remain in the motor. The length of time they remain in the motor is proportioned between the time before and after ignition. The less the delay in ignition, the greater the burning time, accordingly it is best that the propellants arrive at the chamber pre-heated (perhaps through use as cooling agents).

According to the results of the research which follow length of time during which the fuel remains in the chamber must be greater than approximately 1/500 second with a favorable state of operation. This depends chiefly on the relation of the necessary chamber space V to the narrowest cross-section of the exhaust nozzle f'; on the other hand, it depends very little on the other conditions of operations such as the pressure of the exhaust gases or the like.

The relationship between V/f' and no, is represented in Fig. 61, as far as may be ascertained from the tests carried out on a small scale (up to 30 kg thrust) large V/f' or anything above a thrust of 10 to 30 kg is desired so long as the chamber surface that is in contact with the flame does not grow too large, since in this case the heat absorbed by the propellants used as coolants can no longer be controlled and results in a dangerous condition. According to practical experience the first important rule of rocket motor construction becomes evident:

I. "The volume of necessary combustion space in cu. cm. must bear to the area of the narrowest cross-section of the nozzle (in cm^2) the relation of from 50 to 5000 cm."

The best value of V/f' should be looked for somewhere in the vicinity of 500 cm. The best value can be maintained in a motor cooled simply by its propellants only when the motor is relatively powerful—from 500 to 1000 kg thrust—since with these larger motors the relation of chamber wall area to chamber volume is sufficiently small to guarantee proper cooling of the chamber walls by means of the propellants that are to be burned in the chamber; that is, if too high a fuel pressure is not employed.

The nozzle efficiency nd, signifies the degree of completeness with which the heat content Jo of the gases is transformed into effective jet velocity carrying kinetic energy at the rate of $c^2/2g$. It is known that the effective jet velocity c is not identical with the true speed of transpiration of the exhaust jet since it is derived from the effective thrust of the motor—which as a vectorial sum pf the pressure of the gases on all the walls in contact with the combustion, is composed of the instantaneous sum of the impulses in respective nozzle mouth cross-sections plus the pressure of the exhaust gases on the nozzle mouth cross-section (effective thrust = impulse given by speed ahead — pressure impulse — collective thrust mc). For the determination of the nozzle efficiency the customary relation of the transformation of heat content into jet velocity in Laval nozzles is not applicable (for example, line a in figure 61. The effective velocity and therewith the efficiency, already very high with a small expansion ratio f/f' (f = cross-section of the mouth—figure 62) is larger because of the high gas pressures on the small orifice, and grows with an increase in the expansion ratio, but not so rapidly as the true velocity of the escaping gases. The theoretical advantages of a greatly lengthened Laval nozzle of small angle of opening are therefore really less important for rocket motors than, for example, for steam and gas turbines.

Because of the small influence of the lengthened part of the nozzle, dispersion of the stream of gases from the nozzle wall beyond the narrowest cross-section of the nozzle, and the production of a similarly regulated and arranged stream of gases outside of the nozzle has, in great contrast to the turbine, only a slight significance. Therefore lengthened nozzles with great angles of aperture may be altered without perceptible damage to the nozzle efficiency. The nozzle angle can be for example, 180° in which case the exhaust gases after emerging from the narrowed nozzle throat usually follow along the face wall, on which a pressure is accordingly exerted. Because of the decrease of pressure in the direction of the exhaust, the danger of the splitting off of the boundary coating of the nozzle wall is slight. Line d figure 61 shows that the effective nozzle velocity with much greater angles of aperture lies only slightly below those of very long Laval nozzles. Nozzles with flare angles considerably over 180° have practically no meaning. Short nozzles with great angles of aperture have the further important advantage of decreasing the surfaces endangered by heat and erosion. Thereupon follows the second important rule of rocket motor construction:

II. "Expansion nozzles for the exhaust gases of rocket motors should have an average angle of flare over 25° and under 270°."

In practice the best value of the flare angle lies empirically somewhere around 90° The nozzle efficiency in this arrangement is somewhat greater than with a flare angle of 180°, but it does not quite reach the ordinary Laval nozzle with a 10° flare angle, as line c in figure 61 shows.

Efficiency ni, the collective internal efficiency of the rocket motor

$$ni = c^2/2g : E/A$$

is made up of the chamber efficiency and the nozzle efficiency

$$ni = no\ nd$$

Empirically it can reach a value of 70%.

If one takes, for example, a certain fuel mixture—1 part by weight of petroleum and 3.3 parts by weight of oxygen—there is obtained, with the calorific power of petroleum equal to 10,250 calories per kg, a total heat of reaction equal to 10,250/4.3 = 2390 calories per kg, and with this an attainable jet velocity of c = 3,740 meters per second, which has already very nearly been reached during the experiments with the small models mentioned previously. Since propellant mixtures with heats of reaction even up to 5,430 calories per kg are known, velocities of c = 5.650 meters per second appear attainable at least in theory. Operating safety limits us at present to jet velocities of 3,000 meters per second, corresponding to a propellant consumption of 3.3 to 3.5 kg of petroleum and oxygen per second of 1000 kg thrust.

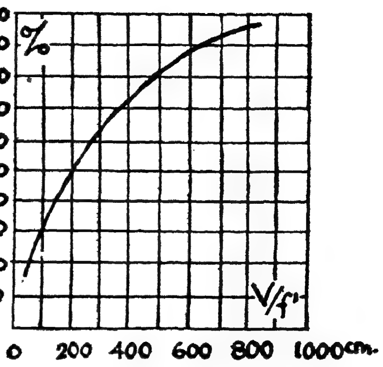
The observed high chamber efficiencies are probably conditional upon the quicket possible combustion under a pressure of 20 to 100 atmospheres with no further decomposition of the gases, so that the flame temperature with oil and oxygen having a heat content of about

$$J_o = n_o E = 0.85 \times 2390 = 2030$$

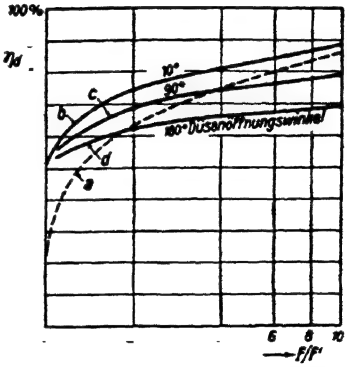
calories per kg

must mount above ordinary combustion temperatures and reach a magnitude of the order of $T_o = 6000°$ absolute. Information obtained elsewhere under similar circumstances points in the same direction as does also the magnitude of the heat loss through the walls of the chamber observed in the experiments. In any case the flame temperatures in the rocket combustion chamber exceeds those of any other type of high-temperature technical furnace, such as the internal combustion engine (2200° abs.), cannon (3000° abs.), or autogenetic welder (3500° abs.). The flame temperature can be reduced through the choice of a smaller V/f' (incomplete burning) or a fuel with a slight E value, however at the expense of the jet velocity. Structural solutions eliminate from the first any application of highly refractory lining of the chamber or of the nozzle without the essential wall cooling since the known substances with the highest melting points (graphite 4000°, tantulum hafnium carbide 3900°, niobium carbide 3800°, thorium oxide 3000°, etc.) do not reach with their melting points the temperature of the flame.

The interesting problem of cooling motors can be brought out in the following simple but fundamental experiment showing that one may protect, by means of cooling, ordinary materials of construction from extraordinary combustion temperatures: An ordinary metal tube (steel, copper, brass, aluminum, or the like) of about 10 mm. internal diameter is connected to a water pipe, and one tries to melt any thickness of it with an autogenetic welder while water is flowing through it. While the superficial poorly conducting layers burn off and melt

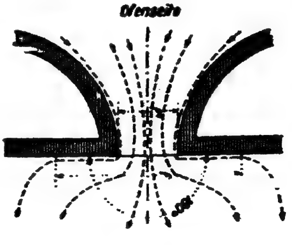


Chamber efficiency, no, plotted against the relation of combustion volume to nozzle throat cross-section



Nozzle efficiencies, nd, plotted against ratio of mouth area to throat cross-section (f/f' — expansion ratio)

FIG. 61



Expansion nozzle for the exhaust gases of a rocket motor having a 180 degree angle of aperture. (gases flow downwards)

FIG. 62

quickly, the metal tube remains undamaged so long as the speed of the water inside it remains high enough. The metal tube is not even visibly warm. Since the welding flame temperature lies about at 3500° abs. and the metal—which is not even glowing—is heated to only a few hundred degrees, the temperature drop in the border layers of the gases of combustion must have the extraordinarly high value of about 3000° abs. (figure 60).

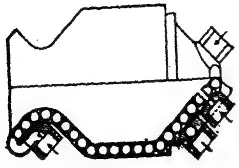


FIG. 63

Use is made of these relations in construction of the rocket combustion motor. Through a series of constructional precautions it is always possible to keep the temperature at the edge of a zone of extraordinary intense combustion low enough to be within the working range of the material of which the combustion chamber walls are constructed, providing the walls are not too thick and have good conductivity. Essentially, these precautions require a lowering to a minimum of the transfer of heat from the gases of combustion in contact with the wall surfaces, and a raising to a maximum of the transfer of heat from the cooler side of the wall to the coolant.

The supply of heat on the flame side of the wall comes principally from the outflow of the gases, in contrast to which convection is unimportant. In the nozzle the temperature of the gases of combustion, and with its fourth power the outflow of the gases, decreases according to the law of conservation of energy.

$$\int \quad c_p / A . X \, dT \qquad c_x{}^2/2g$$

with an increasing jet velocity cx; therefore the convection of the rapidly streaming gases increases rapidly and reaches a threateningly high value with a speed exceeding that of sound. Radiation is minimized through such precautions as: the use of a slightly radiating, diathermous fuel gas (for example, H_2, H_2O, CO_2); silvering to get a brightly reflecting lining of the inner surface of the chamber; its spherical smooth construction; high combustion gas pressure permitting smaller chamber surface and nozzle cross-section with a given thrust—of course at the price of high pump power or heavy pressure tanks.

The removal of heat from the cooler side of the wall to the coolant takes place practically entirely through convection. It is favored by precautions like the use of the coldest coolants (liquid gases) increasing of the surface in contact with the coolant (conduits and ribbed, rough wall surfaces) use of the densest possible coolant of vapors, gases, and liquids under high pressure (danger of vaporization); high velocities of circulation behind even the smallest place on the wall surface in contact with the gases of combustion so as to raise the heat transmission value.

According to all experiments the ordinary circulation of the coolant in machines deriving their power from combustion is altogether insufficient in rocket motors, where the transmission of heat through the walls amounts to about 1 H.P. per square centimeter, and only with a strictly regulated and rapid circulation of the coolant behind the smallest part of the wall next to the fire can such quantities of heat, which are everywhere constant, be carried away without local transmission of heat in the chamber walls. This strong positive circulation of coolant is only possible in spaces of chiefly one dimensional extension (canals). Whereas in explosion motors, gas turbines etc., local failing of the coolant to work due to stagnation or too slow circulation may be compensated for by heat flow within the walls without undue heating, this is not possible in a rocket motor working at maximum efficiency. In view of this, the third important rule of rocket motor construction becomes evident:

III. "The circulation of the coolant along the walls in contact with the flame must take place in canals and must be so positive that it maintains unfailingly at every section of the wall in contact with the flame a velocity of circulation of a prescribed amount." (see Fig. 63).

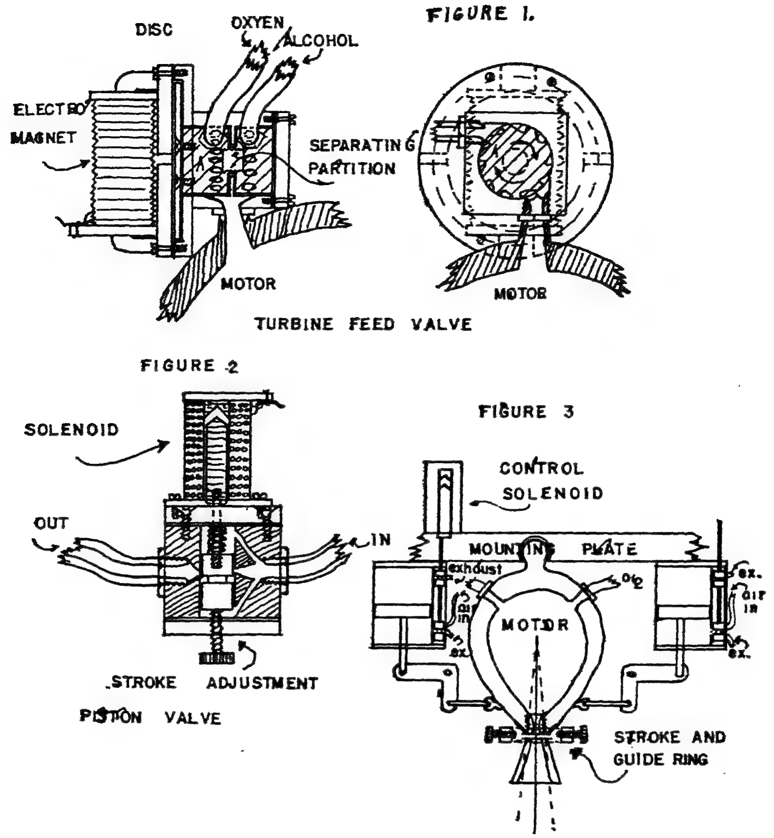


FIGURE 1.
DISC
OXYEN
ALCOHOL
ELECTRO MAGNET
SEPARATING PARTITION
MOTOR
MOTOR
TURBINE FEED VALVE
FIGURE 2
SOLENOID
OUT
IN
STROKE ADJUSTMENT
PISTON VALVE
FIGURE 3
CONTROL SOLENOID
MOUNTING PLATE
exhaust
O2
air in
ex.
MOTOR
ex.
air in
ex.
STROKE AND GUIDE RING

FIG. 64

Above is an interesting diagram for a steering mechanism. Note that the rocket motor swivels upon a mounting plate by means of compressed air. To steer the rocket the angle of firing is varied by operating the compressed air cylinders.

The fuel consumption of a rocket—1.7 to 3.5 kg per sec. per 1000 kg thrust—is very high in contrast to that of the ordinary propeller mechanism. The rocket therefore cannot enter into competition with a mechanism using the propeller as its continuous driving force. Rather, the rocket is fundamentally to be used as a source of impulse which lasts only a short time. The propeller mechanism in the more speedy airplanes yields something like one kilogram throust for each kilogram of its own weight; the rocket motor in contrast yields ten to 50 kg thrust per kg of its own weight. For equal weights the thrust of the rocket is therefore 10 to 50 times higher than that of the propeller mechanism. Hence follows the use of the rocket motor for an output of power over a short period of time.

The thrust of the propeller mechanism decreases with increasing speed of flight, since thrust times velocity is equal to a constant output. In contrast to this, the motive power of the rocket is quite independent of the velocity. The rocket motor is therefore decidedly the source of power for flight at high speeds.

Very real increases in the speed of flight are only possible in the stratosphere in altitudes over 20 km into which no airplane can penetrate with power furnished by the screw action of the propeller. The propeller mechanism needs the surrounding air for its operation for three reasons—its oxygen content for the combustion of benzines, its mass for the proper screw action of the propeller, and its ability to take up heat for the motor cooling—but the rocket motor takes care of all these functions with its own supply of propellants and does not therefore depend on the existence of the exterior atmosphere. Accordingly, just when the propeller mechanism, in altitudes over 15 km is weakening in spite of compressors and exhaust turbines, the rocket propulsor begins to display its advantages since its motive power is undiminished and it permits of the greatest possible speeds of flight. The realms of operation of both kinds of flying craft are therefore clearly separated by their physical limitations; the propeller mechanism as an economical source of impulse for speeds of flight under about 1000 km an hour in altitudes under 15 km; the rocket motor as a source of maximum impulse for short times in starting, ascending, and reaching top flight speeds, about 1000 km an hour in altitudes above 15 to 20 km.

An example of the possibility of adapting the rocket motor economically is its use as an auxiliary to the existing propeller mechanism of pursuit planes.

A modern pursuit plane of about 1700 kg weight in flight, and capable of about 500 km per hour mean horizontal speed, climbs to an operating altitude of 6000 meters in about eight minutes. By the effective use of a rocket accessory permitting this airplane with its speed of 500 km per hour (or 139 meters per sec.) to climb with a favorable angle of ascent of 30°, its operating altitude of 6000 meters would be reached in $t = (6000/\sin 30^\circ)$ $139 = 86$ seconds, inclusive of time of starting — that is, in approximately 90 seconds or 1½ minutes. Under these conditions the propeller mechanism operating with compressed gas as in horizontal flight takes care of the thrust necessary to overcome air resistance (air resistance x forward speed) while the power necessary for ascent (weight x velocity of elevation) is provided wholly by the rocket accessory.

The installation of the rocket mechanism should be possible without important alterations in the airplane — particularly without modification of the present propeller mechanism, or without any appreciable increase in air resistance, even with airplanes already made, so that in this way the economical modernization of antiquated airplanes is possible. By feeding the propellants with high pressure tanks the accessory is made completely independent of the main mechanism or of fuel pumps but also since the propellant pressures are limited, the V/f value must remain fairly low because of the relationship previously pointed out between the volume of the combustion chamber and the coolable wall surface, and this in turn lowers the jet velocity, which however, is unimportant for rocket motors used for this purpose (in contrast to the stratosphere rocket motors). The specific fuel consumption then amounts to about 3.5 kg sec t, so that the help in ascent during the 90 seconds for a motor delivering 1000 kilograms of thrust necessitates a propellant consumption of 3.5 x 90 = 315 kilograms of propellants.

The essential constituents of the ascent auxiliary are the tank installation and the rocket motor. The tank construction must provide that the necessary propellants (oil vapor and liquid oxygen) are fed for complete combustion under a pressure of 50 atmospheres.

The required pressure during the consumption of the propellants is maintained from a special compressed gas container by way of a reducing valve. As a pressure-providing gas, nitrogen is used because of its neutral chemical properties, its insolubility in contact with liquid oxygen, and its cheapness.

Since the fuel oil and oxygen are used in a ratio of weights of 1:3.3, the necessary tank voluve is 85 liters of oil and 215 liters of oxygen. The spherical high-pressure tanks are therefore of 55 cm and 74 cm interior diameter and 6.3 kg and 15.9 kg weight. The spherical pressure gas container, with its contents at 300 atmospheres pressure assuming the expansion of the gas due to the many changes of temperature, can be estimated at about 86 liters contents, 55 cm dimeter, and 40 kg weight; according the nitrogen gas weighs an additional 32 kilograms. This nitrogen gas is calculated as a material to be consumed. After the exhaustion of the supply of oil or oxygen it enters from the corresponding propellant tank into the motor, extinguishes the fire instantly, and flows through the motor to the outside, in so doing completely washing out the motor after the cessation of thrust.

Figure 66 is a schematic arrangement of this ascent auxiliary which does not change the center of gravity of the pursuit plane in which it is installed.

The pressure gas flows from the pressure tank through a release valve and a reducing valve RV which keeps the pressure constant, then through a T fitting to

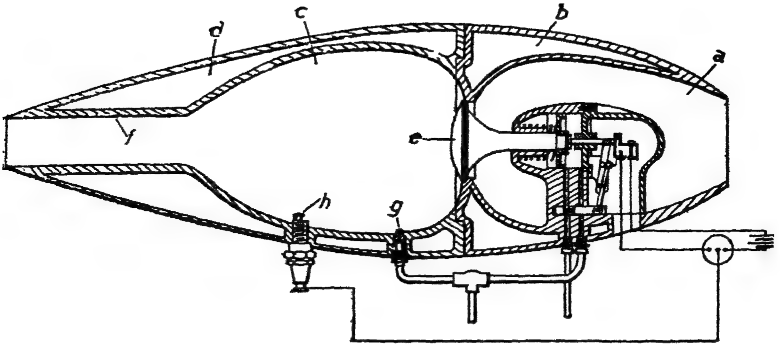


FIG. 65

A pulsating liquid fuel rocket motor. Note the intake valve and the spark plug. This might be a very practical arrangement for a hot air jet-propulsion drive.

the propellant tanks which are thus placed under 50 atmospheres pressure. The oil and liquid oxygen are forced by this pressure through the conduits leading to the motor, and are controlled by the coupled valves KV operated from the cockpit.

The total weight of the apparatus inclusive of mountings:

	Oil tank	7.5 kg
Empty	O^2 tank	19.1
	Pressure tank	47.6 kg
	Motor	10.0 kg
Total		84.2 kg
	Oil	73.3 kg
	Oxygen	241.7 kg
	Nitrogen	32.2 kg
	Accessories	84.2 kg
Total		431.4 kg

The normal pursuit plane of 1700 kg weight has therefore a starting weight of 2130 kg after the ascent auxiliary is installed. By this means its starting speed is raised about 12% and the starting path is shortened about 50% by the influence of the rocket auxiliary. After using the rocket propellants the flying weight is only 1780 kg and during the period of ascent the total weight averages less than 2000 kg; and with this equipment the very high rocket thrust of 1000 kilograms is available through an angle of ascent of 30°—which is an achievement worth considering. The ascent auxiliary improves the time of ascent to [illegible] meters from 8 min to 1½ min.

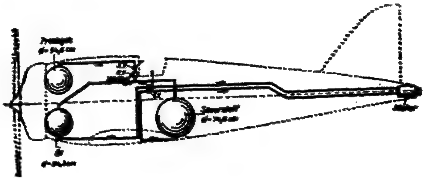


FIG. 66

It would also be profitable to ascend through the lower layers of the air, where the propellor mechanism works well, without using the rocket auxiliary until 4000 meters. In this way the ascent to the upper air layers, which are difficult to reach, would be greatly accelerated. Or the ascent accessory can be repeatedly put into operation during the course of combat, for example in order quickly to regain lost altitude.

A flying craft so equipped is qualified to attack the world's speed record. In horizontal flight at 500 km per hour and and resistance of 2130/e = 2130/8.5 = 250 kg may be assumed for a pursuit plane of 2130 kg weight corresponding to a motor performance of 600 horsepower. After the ascent auxiliary is started and the plane is kept in horizontal flight with the propellor functioning also, the available thrust for overcoming air resistance mounts to about 1120 kilograms, or 1120/250 = 4.5 times the normal value, and the flight speed approaches 4.5 or 2.12 times this value; accordingly it reaches over 1000 km per hour and so surpasses the present world's record. This record speed would be maintained over a period of 90 seconds over a distance of 25 kilometers.

The requirements of the airplane cells do not expire above the degree that in any case is taken as the basis in the static reckoning of the pursuit plane. However, stability and the ability to control the airplane with motive power acting from the rear is in no way different than when the equally great motive power acts on the nose of the body, since the direction of the force remains in a fixed relation to the airplane axis and the point of exertion of the "fleeting line" vectors of force for the mechanical operation of the rigid airplane body is known to be without importance.

A very interesting estimate compiled by a German experimenter in Reich marks (there are approximately four Reich marks to a dollar) and before the war showed that manufacturing costs for the motors plays an entirely subordinate role — for example, the cost of the complete ascent auxiliary should not lie over 2000 reichmarks, the life of the tank equipment is unlimited and that of the motor about equal to that of an ordinary airplane motor.

The price of oxygen can be placed at 0.50 marks per kilogram, the price of oil at 0.10 marks per kilogram. With a propellant consumption of 3.5 per second t, the cost of operation becomes 1.35 marks per second t. As an aid in starting the normal transport plane of 4000 kg starting weight a thrust of 1000 kg through about 20 seconds is required, so that the cost of operating amount to about 30 marks per start together with the pressure gas. As an aid in ascent for the pursuit plane of 1700 kg starting weight a thrust of 1000 kg works through 90 seconds at which time the consumption of the pressure gases enters so that the total operating cost for each ascent becomes about 135 marks. Later stratosphere mail-carrying craft of say 3000 kg net weight plus a 500 kg cargo require, over a 5000 km course, a variable thrust of 9000 kilograms through about 650 seconds during which the total fuel consumption amount to about 12000 kg corresponding to a cost about 2 marks per kilogram kilometer of 4800 marks for the 5000 km flight or for the cost of transporting a cargo at a much higher speed than is possible today.

While very thorough and complate analyses of the basic laws of rocket motion have been made by Goddard, Esnault-Pelterie, Oberth, Sanger, and others, their work is largely varied in abstruse technical treatises which are not generally available and which are principally in foreign languages. It has seemed desirable to resurrect and simplify certain of this material into an accessible and comprehensible form, with a view to clearing up some of the misconceptions which so frequently exist regarding the theory of rocket flight. Such is the purpose of the following elementary discussion. which is based on the work of Oberth and Scherschevsky.

Since most modern work on rockets is directed towards the development of meteorological rockets, only vertical flight will be considered, thus simplifying the calculations. As a starting point, consider a rocket in free space, subject to neither gravity nor air resistance. Its motion is governed by the law M dV = c dM where M = mass of rocket and fuel, v = rocket's velocity and c = exhaust gas velocity relative to rocket, all in consistent units. This is really a force equation, M dV being the force required to accelerate rocket and—c dM being the kick of the escaping gas (negative, because dM represents a decrease of mass.)

Rearranging this and splitting M up into mass of empty rocket Mr and fuel mass Mf :

$$\frac{dV}{c} = -\frac{dM}{M_r + M_f} \qquad 1$$

Integrating:

$$\frac{V}{c} = -\log_e (M_r + M_f) + K$$

Since at the beginning of flight V = O and Mf = initial fuel mass Mfo:

Therefore:

$$V = c \log e \cdot \frac{(Mr + Mfo)}{(Mr + Mf)}$$

which gives the velocity for any value of Mf during flight. The maximum velocity Vm occurs at end of firing period, when Mf = O. Therefore:

$$c \log_e \frac{M_r + M_{fo}}{M_r}$$

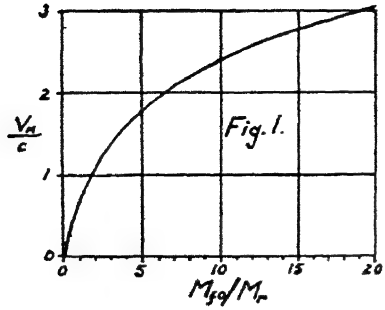


FIG. 67

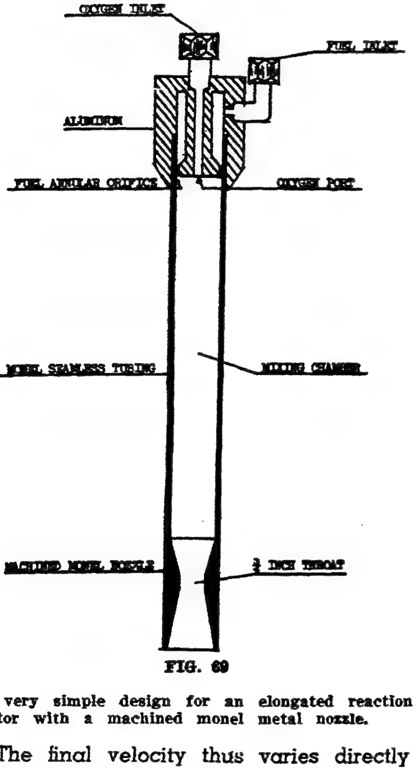

OXYGEN INLET
FUEL INLET
ALUMINUM
FUEL ANNULAR ORIFICE
OXYGEN PORT
MONEL SEAMLESS TUBING
MIXING CHAMBER
MACHINED MONEL NOZZLE
¾ INCH THROAT

FIG. 69

A very simple design for an elongated reaction motor with a machined monel metal nozzle.

The final velocity thus varies directly with the exhaust velocity, nad hence as the square root of the kinetic energy of the exhaust gases (for K. E. = ½ m c^3). For any given fuel, the final velocity varies as the square root of the thermal efficiency, since the K.E. is directly proportional to the latter. It will also be seen that Vm depends on the initial mass which is 100% when V = c, is less than 100% at higher or lower values of V. It is of interest to calculate the value of Vm for which the mean energy conversion is greatest.

The corresponding value of E is 64.7%, which is the maximum value for the energetic efficiency under ideal conditions. It is impossible to obtain a more efficient energy conversion than this under any circumstances.

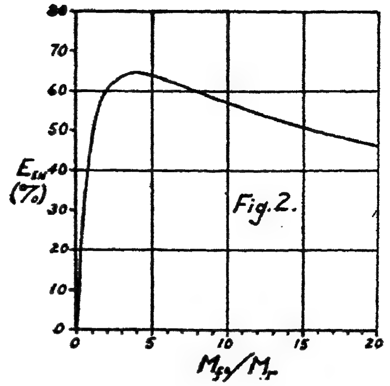


FIG. 68

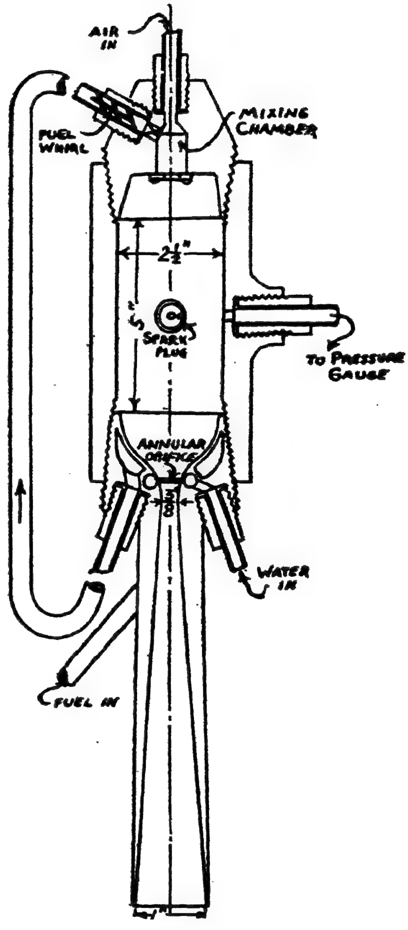
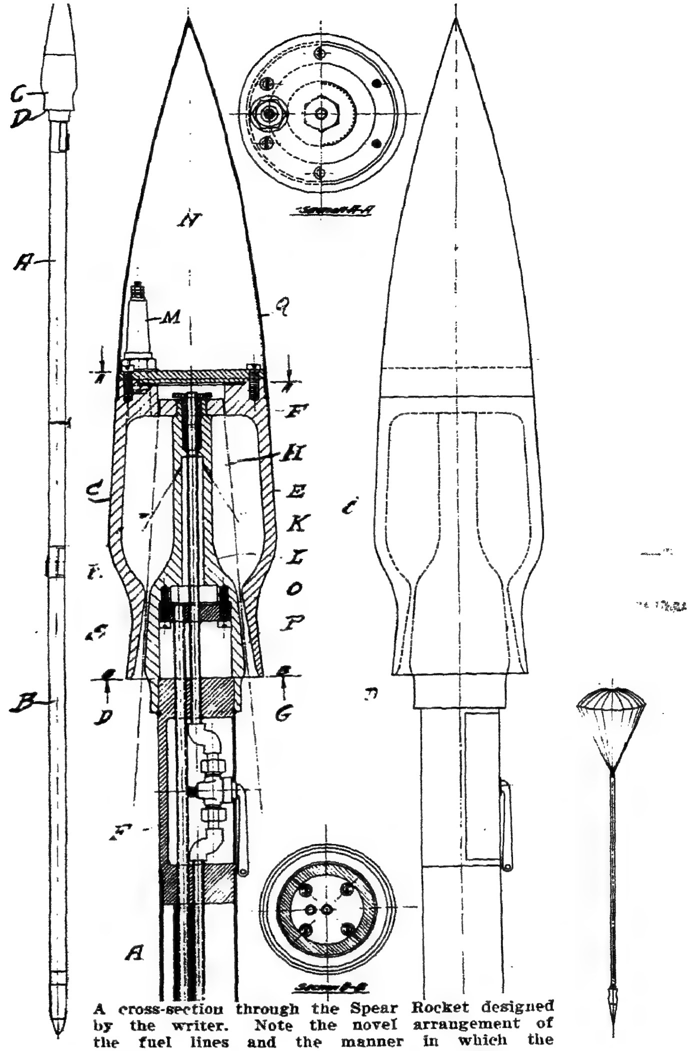

AIR IN
MIXING CHAMBER
FUEL WHIRL
2½"
SPARK PLUG
TO PRESSURE GAUGE
ANNULAR ORIFICE
3/8
WATER IN
FUEL IN
1"

FIG. 70

A semi-degenerative motor. The fuel enters at the base of the nozzle and then continues to the fuel-whial. Water cooling means is also shown.


C
D
A
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M
Q
F
H
E
K
L
O
P
G
D
A
F
C
Section A-A
Section B-B

FIG. 70a

A cross-section through the Spear Rocket designed by the writer. Note the novel arrangement of the fuel lines and the manner in which the Oxygen and gasoline are injected into the combustion chamber.

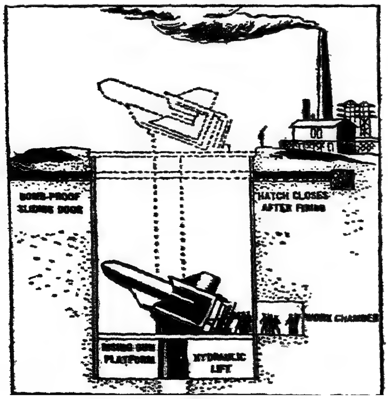
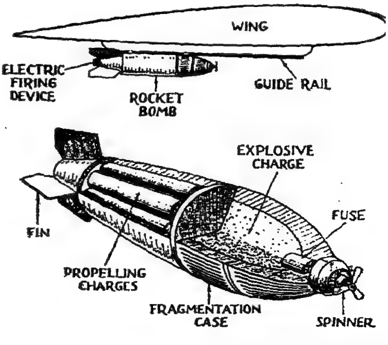

BOMB-PROOF SLIDING DOOR
HATCH CLOSES AFTER FIRING
WORK CHAMBER
RISING GUN PLATFORM
HYDRAULIC LIFT

FIG. 71

Can this be another of the German secret weapons?


WING
ELECTRIC FIRING DEVICE
ROCKET BOMB
GUIDE RAIL
EXPLOSIVE CHARGE
FUSE
FIN
PROPELLING CHARGES
FRAGMENTATION CASE
SPINNER

"Aeroplane" drawing

THE RUSSIAN ROCKET BOMB— A velocity of 800 ft. per sec. gives the projectiles a penetration of seven inches of armour plate.

PRACTICAL APPLICATION OF THE JET-PROPULSION MOTOR

It is generally conceded that one of the first useful fields of application for the liquid fuel rocket when it is adequately developed will be as an apparatus for carrying meteorological instruments into the upper stratosphere. It is therefore of interest to note what requirements it must meet to serve satisfactorily in this capacity, and what advantages it may offer over other techniques now in use.

Although studies of the upper atmosphere have been carried on since the beginning of the last century and even earlier, it is only since the advent of ex-extensive aerial navigation and the modern principles of air-mass analysis that systematic soundings have been maintained. "Air-mass analysis", which is the study of weather formation by determining the characterists and interactions of large horizontally homogenous sectors of the atmosphere emanating from various "source regions", requires a complete knowledge of the vertical properties of the atmosphere over many points on the earth's surface—a knowledge which now falls in the province of meteorology called "aerology". This information, consisting primarily of temperature, pressure, water-vapor content, and wind directions and velocities is now obtained in the United States by daily pilot balloon observations at 77 stations, and by daily airplane flights from about 25 stations. The airplane observations, which include visual reports of cloud forms, precipitation, etc., are made to an altitude of 16,500 feet when practicable; the pilot balloon observations, which consist of wind directions and velocities, and cloud formations determined by theodolite measurements of the drift of small free balloons, are made to whatever altitudes the balloons remain visible and occasionally reach the stratosphere. "Sounding balloon" observations — that is, data determined by automatic recording or transmitting instruments sent up in small unmanned balloons to great heights — are not at present used in regular weather forecasting, but only in special meteorological research, as during international months when upper air sounding are made simultaneously by all weather bureaus represented in the International Commission for the Exploration of the Upper Air.

Precisely how the perfected liquid fuel rocket will fit into this program it is of course impossible to foresee, due in part to evolution in the science of meteorology itself, and in part to the unpredictable operating characteristics of such rockets. However, some general conclusions may be drawn, based on reasonable assumptions and present information.

Even if we assume that no radical change takes place in the science of meteorology, making it more dependent on knowledge of phenomena in the high stratosphere such as rockets are in theory especially qualified to deliver, still the rocket could well be employed in extending the range, effectiveness, and precision of aerological soundings of the sort now executed by other devices—provided, of course, that it attains a certain performance. In other words, if rocket experimenters and designers find it possible to develop a comparatively small and inexpensive machine that is simple to operate, it could be used to good advantage by weather bureaus to take over various functions now discharged by pilot balloons, airplanes, and sounding balloons.

A very general description of the necessary operating characteristics of such a standard "stratosphere sounding" or aerological rocket may be attempted. First, it should be able to ascend vertically from five to ten miles and then descend by parachute at a predetermined rate. It should be able to repeat this performance regularly and with the minimum of upkeep, adjustment, and propellant consumption. Its rate of acceleration should not exceed two or three gravities, or whatever figure is arrived at as reasonable for the preservation of recording instruments. It should be capable of carrying a meteorograph for recording temperature, pressure, and humidity and weighing one or two pounds.

Assuming that such a rocket uses a motor that operates on a gasoline-oxygen propellant charge at a thermal efficiency of 20%, that it weights 22 and carries ten pounds of propellant (giving an energetic efficiency of about 40%) that it accelerates at an average of 3 gravities (hence a dynamic efficiency of 75%), that its "air resistance efficiency" is about 40%, then such a rocket would operate at an over-all efficiency of over 2%, and its charge of propellants containing about 33,000,000 foot-pounds of energy would be able to drive it to an altitude of about

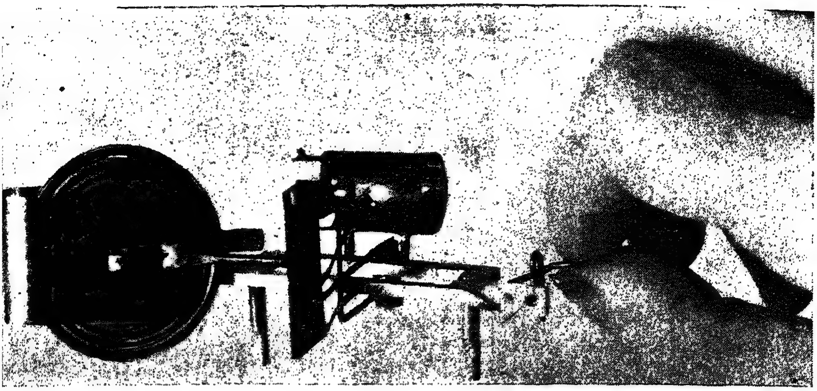


FIG. 73

The Jaumotte micro-meteorograph. It weighs only 45 grams complete in case, and gives a record of temperature and relative humidity against pressure on small smoked glass plate slightly larger than a postage stamp.

eight miles. The duration of the shot would be about a minute or a minute and a half.

The meteorograph carried by a rocket of this type could be substantially the same as those employed in present sounding balloons except that it might need to be somewhat heavier and more rugged. Meteorographs now in use having bimetallic temperature element, hair hydrometer and aneroid cell, together with clockwork recording drum, weigh 175 grams or less. The instrument would be held in a locked position during the vertical flight and would be set in motion by the same device that actuates the parachute release at the apex of the shot, so that it would record on the way down instead of on the way up as with sounding balloons. The speed of descent could be easily regulated by the size of the parachute, and velocities as great or greater than the highest reached by sounding balloons (about 1500 feet per minute) could be easily attained.

The advantages of such a system of aerological soundings are as follows: 1. A substantial reduction of the time required for the process due to the rocket's high speed and the rapidity of descent. Airplane soundings often require several hours, and balloon soundings not much less, while the rocket could ascend to the substratosphere and return in ten or fifteen minutes. 2. By the same token, a far more nearly vertical cross-section of the atmosphere would be obtained, which is very desirable. 3. The horizontal drift would be reduced to a minimum. This is a serious factor in the operation of sounding balloons, which often drift tens or even hundreds of miles before landing and not infrequently are either lost or are found only after a long period. 4. Vertical soundings to an altitude two or three times greater than with airplanes could be obtained regularly, independently of weather conditions. 5. The drift of the descending rocket and parachute could be measured by theodolites from the earth and upper winds charted without the use of pilot balloons.

The deciding factor in such a program would be the cost of building and operating such rockets, and at this stage of development this is difficult to foresee. However, it is safe to say that once a successful type of rocket motor and rocket is achieved, fabrications costs will not be high, as one of the principle characteristics of this engine is its extreme simplicity compared to other prime movers. A small standardized rocket weighing fifteen pounds empty should certainly be built for a few hundred dollars and the instruments it would carry should cost no more than those necessary in any other method of aerological sounding. Propellant consumption, amounting roughly to a quart of gasoline and a gallon of loxygen, should amount to not more than two or three dollars per shot. This is less than the cost of one of the rubber balloons used in a sounding balloon ascension. Interest on the original cost of the rocket plus its upkeep would probably be more than made up for by the "mortality rate" of meteorographs sent up in sounding balloons (11% of all meteorographs sent up in sounding balloons from 1904 to 1926 in the United States were lost permanently) and by the investment necessary in reserve meteorographs for use with sounding balloons while those in the field were being found and returned. As compared to the cost of sounding by means of airplanes, the expense of employing a small machine such as the aerological rocket should be far less than that of employing a large and costly machine such as an airplane, which must be piloted by a licensed transport pilot.

Some writers have suggested that meteorological rockets should be so constructed that the instruments and the empty rocket shell descend on separate parachutes, presumably with the idea that the light instruments could be allowed to descend more slowly. However, since provision must be made for the safe descent of the rocket anyway, and since this plan makes necessary the tracing of two objects instead of one, it seems hardly advantageous. To facilitate location of the rockets, a small radio tone emiter (which can be built weighing only an ounce or two) could probably be included in their equipment, and a scout car provided with a loop aerial to follow them. Even in strong winds, such rockets would never drift more than ten miles from the launching station, because of their free fall. Even if quick recovery proved not always feasible, radio-meteorographs as used in the latest sounding balloons could be used instead of ordinary recording meteorographs, so that the data could be received instantly. Such radiometeorographs can at present be built weighing one pound and with a transmitting range of 100 miles or more.

As the altitudes to be explored increase, the superiority of the rocket becomes more clearly marked. If at a future date a program of stratosphere sounding as intensive as present-day troposphere sounding is achieved by weather bureaus, the rocket will be the machine par excellence for the purpose. For this task we must envisage a more powerful projectile than the aerological rocket of the preceding discussion, which was conceived as simple as possible so that its use might be economically feasible in all upper-air stations that now employ airplanes or pilot balloons. A high-altitude rocket such as this might weigh in the neighborhood of forty-or forty-five pounds (including six or eight pounds of instruments) and carry 40 pounds of propellants. Because of its larger size and power, such an apparatus would have better performance characteristics than the trotosphere rocket. Air resistance efficiency would mount substantially, since the major portion of the trajectory would lie in very rarified atmosphere. The thermal efficiency of the motor would also be higher, because of its larger size and more refined design, and it could burn a somewhat more powerful fuel such as benzol, since the operation conditions would make its use practicable. Assuming an air resistance efficiency of 70%, motor efficiency of 25%, acceleration at 3 gravities (dynamic efficiency of 75%) and with an energetic efficiency of about 40% determined by the propellant to deadweight ratio of about one to one, the resulting over-all efficiency becomes better than 5% which enables the forty pound benzol-loxygen propellant charge to lift it to an altitude of about 20 miles. The time of ascent would be 2 or 3 minutes.

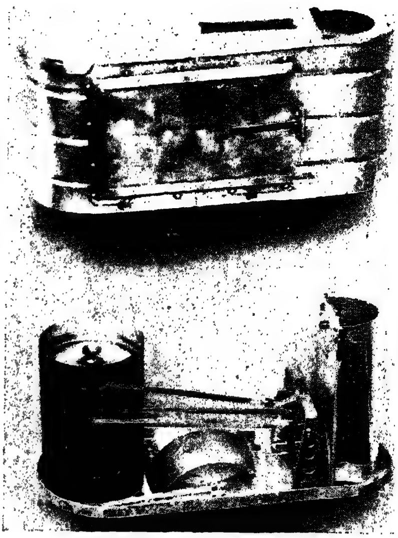


FIG. 74

This is a sounding balloon meteorgraph. It weighs 200 grams complete, which is about 0.44 of a pound, and gives a continuous record of barometer pressure, temperature and relative humidity. The instrument proper is shown below while upper item is the aluminum protective cover.

The meteorograph carried by a rocket of this type would have to be of a radically different design from those in use at present, because of the conditions under which it would have to operate. Since the upper two-thirds of the trajectory passes through air too rarified to operate a parachute (parachutes attached to instruments dropped from manned stratosphere balloons do not even open at heights of ten miles or more) the recording instruments would have to be designed to function at very high speeds—in fact, during upward flight. The barograph, for instance, would probably record the dynamic pressure due to the airflow

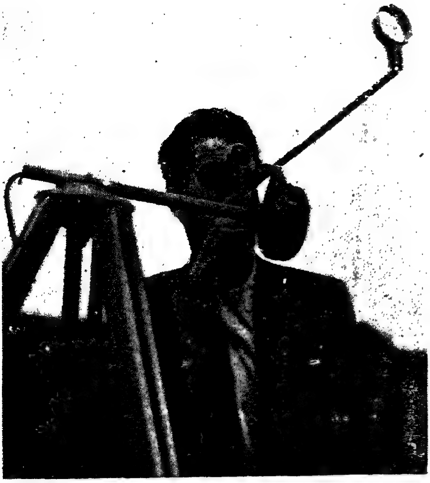


FIG. 75

A simple range finder as shown above can be used to determine rocket trajectories up to heights of 2,000 feet. Above 2,000 feet more complex instruments must be used.

through some sort of a Pitot tube arrangement, since reading the static air pressure at such speeds would be most difficult. (This factor must be taken into account to some extent with Friez-type areo-meteorographs when mounted on airplanes). In like fashion the temperature recording instrument—possibly a modification of present resistance thermometers—would have to be corrected for the dynamic effect of the air-stream.. Probably the most difficult problem would be the design of a hydrometer capable of reacting rapidly and accurately enough for use at such high velocities. All instruments would probably be calibrated for use in a small variable-density wind tunnel.

A sounding rocket so equipped would secure a complete record from ground level to 20 miles height of the three major characteristics of the atmosphere necessary for air-mass analysis and the study of dynamic meteorology. It is even possible that it might be equipped to record the direction and intensity of horizontal winds at various levels, by means of two sensitive recording accelerometers acting at right angles to the horizontal plane, and with their orientation maintained by gyroscopes. At the apex of the flight, all instruments would be locked and the projectile would begin its fall back to earth. A strongly constructed parachute of small diameter would allow it to drop at very high speed to within a mile or two of the surface, when a larger parachute would open allowing it to drift the rest of the way. The whole process would be over in a few minutes, and the horizontal drift would be negligible. The wings of the rocket can be also used in place of a parachute as it is illustrated in Figs. 77 and 80, which are showing such an arrangement as used by Raymond Tilling's rocket.

To coordinate their readings with the altitude and velocity of the rocket, a simple accelerometer could be made to trace its curve on the same recording drum. From this could be calculated the velocity and altitude for all points along the trajectory, so that the proper correcting factors could be applied to the readings of the other instruments. This last operation might even be done mechanically.

Systematic high-altitude soundings carried on by such a device would be incalculably valuable to the meteorologist, since they would yield detailed information as to the structure of the upper atmosphere and its fluxions, laws of circulation, relation to phenomena in the troposphere, climaatological cycles, etc., etc. With regard to the importance of research of this kind, a statement of Dr. J. Bjerknes is particularly opposite: " . . . much further investigation of the mutual interaction of the stratosphere and troposphere in the genesis and development of our weather phenomena will be necessary before we can hope to really understand these processes and to forecast the weather with complete accuracy." Improved balloons and radiometeorographs to facilitate this study are now being developed by meteorologists in various centers (as the Blue Hill Observatory, U.S. Bureau of Standards, California Institute of Technology) but once rocket experimenters have developed their devices to an adequate point, there is little doubt that they will be adopted for such purposes.

Rockets of the more powerful type discussed would of course be too expensive and would require too specialized handling to use except at central stations, but even so it is doubtful that they would represent any greater investment either of money or of skill than the airplanes now used for aerological sounding, which are elaborately equipped with many instruments such as directional gyro, radio transmitter, artificial horizon, etc., and which are piloted by highly trained men. In addition to securing almost instantaneous records of atmospheric conditions to

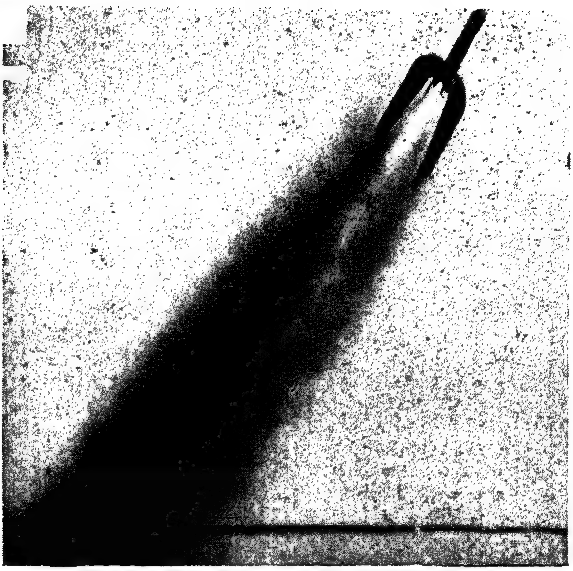


FIG. 76
A nice photograph of a gun-powder rocket zooming skyward. Compare the size of the fins with the portion of the rocket containing the charge.

heights utterly impossible for any heavier than air craft, such rockets could at the same time be used in programs of geophysical and astrophysical research which would vastly extend their usefulness. Special instruments could be installed for this purpose, such as electroscopes, air samplers, cameras, etc. However, such considerations lead into other fields of application too extensive for discussion in this section, restricted as it is to the aerological rocket, which from the point of view of the rocket experimenter is only the first useful application of an engine of almost infinite potentialities.

In the foregoing discussion the performance characteristics of the hypothetical sounding rockets are of course only rough approximations, though they are based on the known lows of rocket motion and such experiments and calculations as are available. The motor efficiencies are assumed greater than any so far attained with rocket motors burning fuel tained with rocket motors burning fuel and liquid oxygen (12%m by Professor Goddard) but are substantially less than those of other types of rocket motor that have been built and tested (45 to 70%, by Sanger of Vienna).

Rocket men have for years been dreaming of the day when rockets would become "practical"— that is, useful instruments for upper air exploration, transport of mail or express, or able otherwise to serve some purpose beside the experimental.

How near we now stand to that moment depends upon the definition of a "practical" rocket.

The replacement of airplanes in upper-air meteorological investigation is the least difficult task a practical rocket could perform. At present, the Weather Bureau, in cooperation with Army Navy and private flyers, sends up airplanes daily from various points, carrying instruments to measure the temperature, pressure and relative humidity of the upper air. This information is used in the new technique of "air mass analysis".

For such work the airplane presents certain unsatisfactory aspects. The cost of ascents is sufficiently great to discourage much use of them. They are more or less dependent on the weather, and the exploration of the upper atmosphere is difficult if not impossible under certain conditions, such as severe thunderstorms, clouds in which icing occurs on aircraft, etc. The time required for plane flights precludes frequent ascents for data.

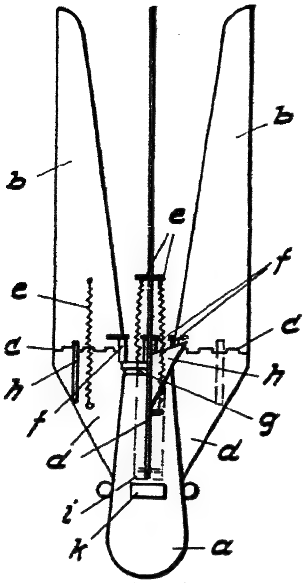


FIG. 77

A diagramic view showing the Tilling rocket with the wings in folded position.

Airplanes are supplemented by sounding balloons; but these, too, have many drawbacks. They do not rise vertically except in perfectly calm weather; they drift miles. Frequently the instruments they carry are not found. This means complete loss when the instruments are self-recording. Since the balloon rises until it bursts, a new balloon is required for each ascent.

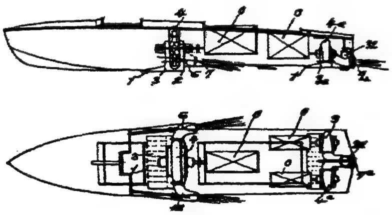


FIG. 78

A Campini design of a jet-propelled boat. The intake of water is as indicated at 1, and the discharge or exhausts at 7 and 7a.

Rocket experimenters have been saying that the rocket could overcome all these difficulties. Instrument-bearing rockets could be sent up hourly from hundreds or thousands of points; could rise vertically to the required distance, penetrate any weather formation, complete a flight in a few minutes, and land safely with self-recording instruments intact.

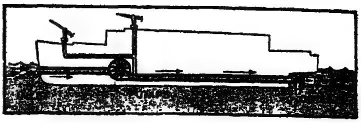


FIG. 79

Another interesting design of the Handley fireboat. The inlet is in the forward portion of the boat with discharge at the rear.

Several authorities in this field were interviewed with a view to jotting down some weather-rocket specifications which would satisfy meteorologists. They were practically unanimous in their opinion of what a weather-rocket should be able to do.

A practical weather-rocket must:

1. Reach an altitude of at least three miles.
2. Carry a payload of approximately two pounds.
3. Be simple and safe in operation; capable of being racked, fueled and fired by one, or not more than two men.
4. Consume not more than $20 in fuel and repairs at each shot.
5. Be capable of vertical shot with not more than 10 degrees deviation.
6. Be capable of announcing its whereabouts automatically and continually, at least while on ground at end of shot.
7. Descend with an impact velocity on coming to earth of not more than 750 to 1000 feet a minute.
8. Be so little damaged upon landing that rocket and instruments could be successfully refired upon refueling.
9. Land within half a mile of the launching rack.

Most of these specifications explain themselves.

Three miles is the minimum now reached by airplanes for meteorological work. Radio-meteorographs used by the Weather Bureau on sounding balloons, making a continuous rport back to the earth by means of radio signals, weigh about two pounds.

The question of cost of each shot is important, for if rockets are to replace airplanes and sounding balloons, they will not only have to perform the work better,

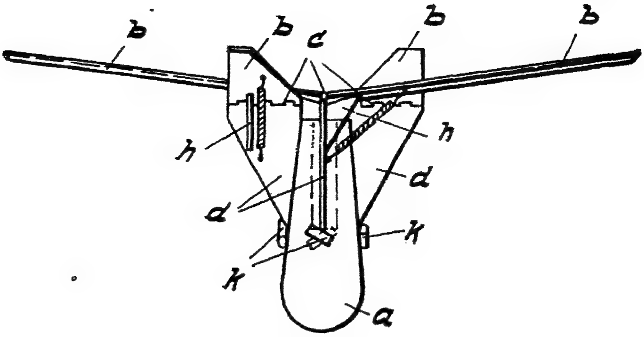


FIG. 80

Above is a view of the Tilling rocket shown in Fig. 77, with the wings open.

but at an outlay near or under that of present equipment, shot for shot. The cost of average plane flight for meteorological data is estimated at $20 to $25. The average sounding balloon, used only once, costs approximately $2.25. In order for the rocket to compete, the fuel cost of each shot and also the depreciation on the rocket must be counted. For example, if the rocket is capable of only twenty shots before it wears out or requires extensive repair, 5 per cent of the total cost of the rocket must be added to the fuel and minor repair costs arising from each shot.

The rocket must go nearly straight up to reach its objective in the last possible time, with the smallest expenditure of fuel. The setting of permissible deviation at 10 degrees from the course is somewhat arbitrary, but this is deemed sufficient to permit the "hunting" that might attend the use of gyro or other stabilizing devices.

Even in the best light, a rocket will probably not be visible at three miles; consequently some simple, sure and easy method of keeping track of it, particularly until discovery on the ground, must be provided. The simplest, probably, would be the emition of a single radio tone, tuned to suitable ground instruments. For a simple range finder see Fig. 75.

Much help in the preparation of these specifications was obtained from the Weather Bureau; particularly from Dr. C. C. Clark, Acting Chief of the Bureau, who sent detailed information in response to a questionnaire referred to him by Dr. James H. Kimball, Chief of the New York Weather Bureau and member of the American Rocket Society's Advisory Board.

Dr. Clark's replies to specific queries were as follows:

"1. The minimum altitude required of a rocket for use in meteorological work depends upon the use to which the data obtained thereby are to be put. For example, if the rockets are intended to replace airplane weather observations, the minimum altitude required would be set at five kilometers (about 16,520 feet). If the rockets are intended to reach the stratosphere in these latitudes, the minimum altitude required would be usually from about twelve to eighteen kilometers. If they are intended to replace sounding balloons and to reach altitude beyond the base of the stratosphere, a suitable minimum might be set at twenty-five kilometers.

2. The 'pay-load' which a meteorological sounding rocket would need to carry depends upon the requirements made of the records obtained from the instrument associated with the rocket. For example, if it were desired that the instrument record pressure, temperature and humidity as functions of time, a clock would have to be included in the mechanism and this would add an appreciable weight. If no clock were required, the mechanism could be much simplified and this would save some weight. As examples of the weight of self-recording instruments which meteorologists employ with sounding balloons it may be stated that one instrument with a clock, used by the Weather Bureau, weighs about two hundred grams (about 7 ounces avoirdupois) while another instrument without a clock weighs about forty-five grams, but presumably, for use in connection with rocket investigations, an instrument of perhaps one hundred or more grams would be more desirable than the lighter ones just specified. It is not practicable to give an

accurate upper limit for the weight of the instrument to be carried in rockets, since various questions of design are involved which cannot be foreseen until actual experience is gained by the development and experimental use of the proposed instrument. It is probably that more rugged parts would be necessary in connection with rockets than are employed in the instruments carried aloft on sounding balloons at the present time.

"3. Radiometeorographs, which are instruments of the type used by the Weather Bureau on sounding balloons making a continuous report back to earth by means of radio signals, now weight from one to two pounds. In this connection, the considerations regarding actual weight in an instrument especially designed for use on rockets, are essentially the same as indicated in question 2 above. It appears probable that the delicate parts of the radio transmitter employed in such an instrument would require special shock absorbing mountings, which would add appreciably to the weight of the instrument if adapted to use on rockets.

"4. It appears probable that meteorological instruments for application to rockets can be designed to withstand an acceleration as great as three times that of gravity.

"5. The sounding balloons carrying meteorographs released by the Weather Bureau all have parachutes which retard the fall of instruments after the balloons burst. From observations at hand, it appears than an impact velocity on coming to earth of from 750 to 1000 feet per minute would be satisfactory. Impact velocities greater than the larger figure would probably lead to an appreciable damage of the apparatus and consequently, it is possible that a parachute would be necessary if the instrument must be salvaged."

If we are in substantial agreement that the specifications outlined in this survey are indeed the minimum ones for a practical meteorological rocket, the question remains: could such a rocket be made?

Various considerations lead to the conclusion that it could. Experimental motors recently used, though by no means perfect, are nevertheless efficient enough to give an altitude in excess of eight miles. The two-pound pay-load does not seem an insuperable obstacle. Providing the rocket with a means of signalling its position would require little more than the invention of a gadget, of which several types have already been suggested.

Points 7, 8 and 9 are really all part of the same problem. It must be confessed that landing devices are still susceptible of considerable improvement. A carefully planned series of tests with dry fuel rockets ought, however, to yield a satisfactory method of releasing the parachute at the right moment, or lead to the development of rotating wings which could land the rocket and its fragile cargo surely and lightly, and within the required half mile of the point of ascent. (See Figs. 77 and 80).

The question of flight cost is at present a totally unknown factor. Liquid oxygen, assuming the rocket were fueled with liquids, is still expensive, but if demand were to develop, it could surely be brought well below the present general price of $1.50 a quart. It would be important to provide a motor that does not burn out, or at least one in which the nozzle, or its liner, could be quickly, simply and cheaply replaced after each shot. There are so few other working parts on the rocket, exclusive of the guiding mechanism, that a well-constructed one should outlast many flights, provided the landing apparatus worked out according to specifications.

Chief doubt about our present ability to produce a suitable weather rocket revolves, finally, around three quite dissimilar points: (a) the rocket must make a nearly vertical flight, (b) it must be safe and simple to operate, and (c) suitable instruments must be devised to gather weather data under the peculiar conditions of rocket flight.

As to the first, many are convinced that we must provide a steering mechanism, which inevitably will add to the weight and complication of the rocket. Some believe that the question of vertical flight can be managed by proper aerodynamic design alone, by rapid acceleration or other such means. The sensible course, obviously, would be to take full advantage of aerodynamics, accelerations and inherent stability; yet make doubly sure of vertical flight with auxiliary apparatus.

The question of safety and simplicity; if indeed this be only one question, and not two; has yet to be tackled adequately. It ought to be possible to assure the operator that the fuels could not become accidentally mixed under any condition; that the motor or tanks simply could not explode, any more than they do in a modern automobile, and that the rocket will go straight up when launched, not run amok and threaten the operator and bystanders.

As to simplicity: the rocket ought to be so easily fueled through such accessible ports, that no Houdini is needed for the

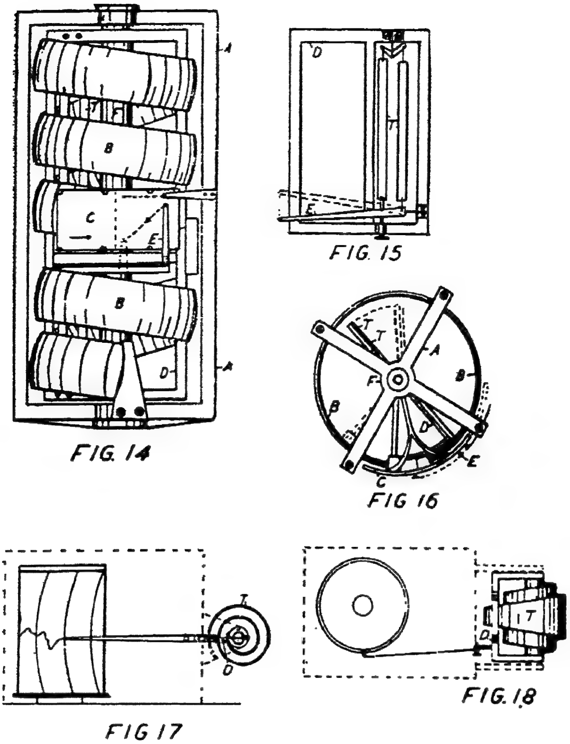


FIG. 81

Dr. Fergusson's weather rocket instrument can be used for measuring temperature, pressure, etc., at higher strata. The instrument shown comprises a plurality of rotating drums. A curve is recorded upon each of the drums by means of a stylus.

job. No waiting period should be necessary after fueling, but if a wait should occur, adequate safety valves should relieve all dangerous pressure. The launching rack ought to be so devised that one man could place the rocket in firing position without help. The firing should be accomplished from fusee to valve release with the pressing of a single key, the lighting of a single fuse, or the pulling of a single, easily-operated cord. For a practical design of a weather rocket see Fig. 53.

The problem of developing rocket-borne weather instruments has been so inadequately studied that little can yet be said on this point. Dr. Clark says:

"It is desired to point out that when the rocket passes through the air at high speed, the meterological measuring elements do not respond quickly enough and, therefore, do not record accurately the condition of the air being traversed.

"This involves several problems, the solution of which may require considerable investigation."

So far as the writer knows, a really successful and foolproof parachute or other landing gear release for use on liquid fuel rockets has not yet been built, perhaps because enough attention has not been devoted to this phase of rocket development. The importance of such a device is self evident, and hardly needs to be enlarged upon. This section is written in the hope that interest will be stimulated in the subject, and more independent experimental work will be done on parachute releases. Such work does not require any elaborate equipment, and the tests can be made with powder rockets.

A satisfactory parachute release has to fulfill certain basic requirements, as outlined below.

1. A premature ejection of the parachute must not take place.

2. The release should positively function when the rocket begins to lose altitude, and be independent of any other factors whatsoever, such as the orientation or any lateral motion of the rocket.

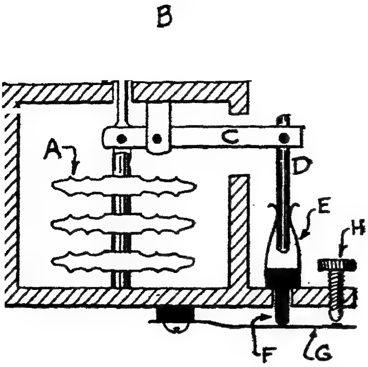


FIG. 82

Another simplified arrangement for a barometric parachute release. The expansion of the bellows A operates the push button E which in turn operates the electric switch G releasing the parachute.

3. It must not be thrown out of adjustment or affected by vibration, shocks, or forces of acceleration.

4. The weight and size should be kept down to a minimum consistent with reliable operation.

In practice the parachute is carried in the rocket in a special compartment, from which it is ejected at the roght moment. Should the main parachute itself be forcefully ejected, there is some danger of fouling the shroud lines, so it is more desirable to make the release eject merely the pilot parachute, which will in turn unfulr the large one.

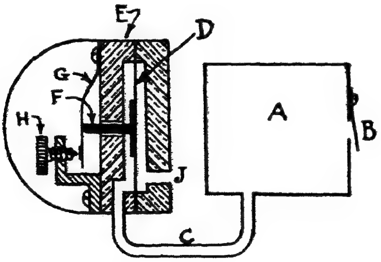


FIG. 83

A simple diagram of a barometric release mechanism. The diaphram D contacts the push button F which in turn operates the electric spring contact G. When the rocket reaches low pressure strata of the atmosphere the pressure differential in the diaphram D operates the electric switch to release the parachute switch.

The ejecting device may be variously constructed, and may depend upon the action of a spring, a blast of compressed gas, or an explosion of gunpowder. The latter method is simplest and has been most often used, as the charge of powder can be ignited electrically by means of a fine resistance wire and a miniature battery. ne disadvantage of the method, however, is the danger of burning the parachute.

The ejection of a parachute by compressed gas involves some slight additional complication of mechanism. The writer has not heard of the method being used, yet it appears that because of its freedom from the danger of burning the parachute, it merits further attention.

The charge of gas might be held in a very small tank, connected to one of the main rocket tanks by means of a fine tube, with a check valve, such as a tire valve, in the line.

Thus the tank could be charged automatically during the flight of the rocket, and yet when the main tanks are empty the small tank will still hold its compressed gas. A carbon dioxide "Sparklet" capsule might also be used. The blast of gas might be released by a special valve, or better still, by a spring operated firing pin, arranged to perforate a soft metal diaphragm in the tank. The blast of gas thus released, instantly fills the parachute container, and ejects either the pilot or the main parachute, as the case may be. The trigger releasing the firing pin may be operated mechanically or electrically by a small solenoid.

There are numerous methods of actuating the landing gear simply by the release of a spring, Reinhold Tilling, among others, has used this scheme in connection with his powder rockets. The springs were released at the moment the powder was used up, and pulled a number of rather large guide fins out of line, which fins then acted as wings to effect a safe descent of the rocket, Tilling was the first experimenter to achieve a considerable degree of success with this method. In some o fhis models the wings made the rocket act as a glider, while in others, the whole rocket was made to spin rapidly about its axis, the fins acting as autogyro wings. (see Figs. 77 and 80).

This method offers some definite advantages over the parachute, as there is always a chance of the parachute not opening properly, of the shroud lines getting tangled up, and various other mishaps. It requires, however, a more careful design of the rocket. The wing area

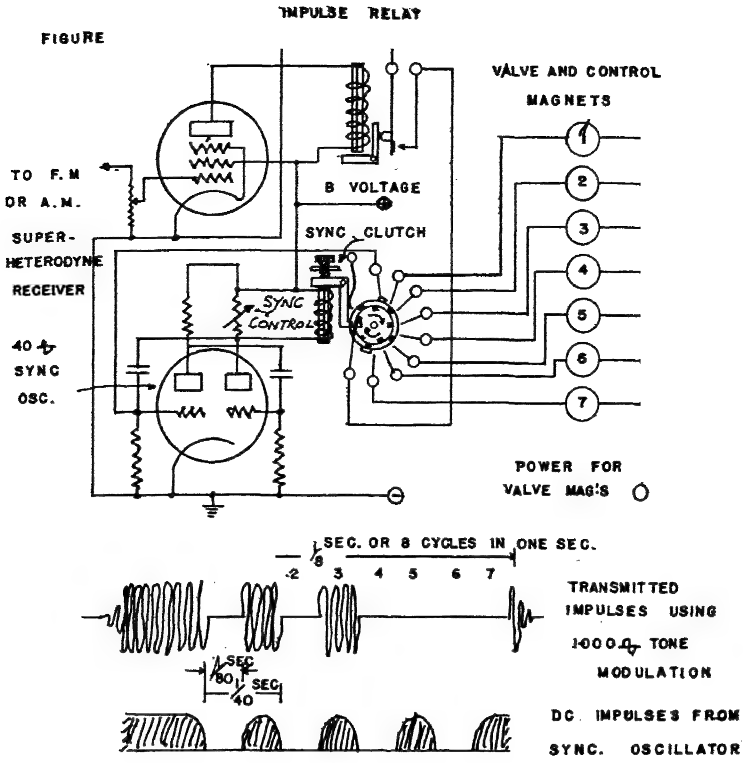

IMPULSE RELAY
FIGURE
VALVE AND CONTROL MAGNETS
1
2
3
4
5
6
7
TO F.M OR A.M. SUPER-HETERODYNE RECEIVER
B VOLTAGE
SYNC CLUTCH
SYNC CONTROL
40 ~ SYNC OSC.
POWER FOR VALVE MAG'S
1/8 SEC. OR 8 CYCLES IN ONE SEC.
2 3 4 5 6 7
TRANSMITTED IMPULSES USING 1000 ~ TONE MODULATION
1/80 SEC
1/40 SEC
DC IMPULSES FROM SYNC. OSCILLATOR

FIG. 84

Above is a diagram for a rocket radio control. The impulses received from the transmitter on the ground operate the fuel valves and the steering mechanism of the rocket.

must be adequate to sustain the weight of the rocket, and yet, the wings must fold in such a way as not to offer undue air resistance during the ascent. The wings must be lightly built, and still be rigid enough to withstand the air impact and cantilever beam loading.

In large liquid fuel rockets, particularly those of long and thin cross-sections, the wings must needs be mounted on a bearing so as to spin freely without rotating the rocket itself, for such rapid rotation might prove detrimental to the rocket should any out of balance condition exist.

Whatever the type of landing gear or arrangement in the rocket, the trigger mechanism which sets off the release is really the most vital part of the whole assembly. The operation of the trigger is made to depend upon some phenomenon connected with the behavior of a rocket in flight. The devices so far used or proposed can be roughly divided into four types according to the phenomenon utilized, to wit:

1. A predetermined lapse of time.
2. Gravitational effects.
3. Air pressure on the nose of the rocket due to forward motion.
4. Barometric effects.

One of the earliest devices used by the Germans consisted simply of a photographic timer, or even a length of slow burning fuse, so contrived as to explode the powder charge after a lapse of time that the designed thought was "about right". The tank pressure method of release is an elaboration of the same scheme. When the tank pressure falls to zero, presumably at the end of the flight, a special catch releases the parachute, either at once, or after a suitable delay to allow for free flight. The time method is open to criticism from the standpoint that it is well nigh impossible to determine in advance the duration of flight. Besides it gives no protection at all in case a nozzle burns out or the motor misses fire in the air, or any other one of the many things that may happen.

The utilization of forces of gravity and acceleration offers many possibilities. When a rocket ceases firing it becomes a freely falling body. The gravity acts upon the rocket as a whole, but any mass within the rocket experiences no downward pull with respect to it. At the end of the firing the rocket will generally have a high forward speed, and the air friction will produce rapid decelaration. This effect will cause any free body in the rocket to develop a force upward. These phenomena have been suggested to operate pendulous devices, mercury switches, escapement mechanisms, etc.

One of the simplest aplications of the above principle was used by the writer on the A.R.S. No. 4 Rocket. The head of the rocket had a fairly heavy, loosely fitting cap with a delicate spring underneath, designed to throw it off and release the parachute at the peak of the flight. During the upward coasting period the air resistance held the cap in place. However, the one time the rocket made its flight the device failed to function.

The air resistance type of release depends upon the increased pressure on the head of the rocket when it is traveling forward at high sped. A Pitot tube on the head of the rocket operates a diaphragm coupled to a switch through the medium of an escapement mechanism in order to prevent a premature discharge.

Parachute releases of the gravity, accelerated and air resistance types, albeit quite sound theoretically, have one fault in common. If the rocket does not come to a stop at the peak of its trajectory, but describes some sore of parabola, traveling at high speed, the release will not work.

Barometric devices seem most likely to be the key to the ultimate solution of the problem and are deemed worthy of more detailed discussion. Their chief advantage is that they depend solely upon the ascent of the rocket, irrespective of other disturbing factors.

One type of barometric release is shown in Fig. 82. The delicate parts are drawn somewhat out of proportion for the sake of clarity. A number of aneroid cells, such as are used in barometers (A) are held distended by an adjustable spring (B). A lever, or a system of levers, as at (C) causes the rod (D) to move up or down. As the rocket ascends, and the barometric pressure drops, the evacuated cells (A) expand and the rod (D) moves down. It slides between two delicate spring blades (E). These blades are attached to the hard rubber button (F), thus allowing the insulated switch blade (G) to rise and contact the screw (H). A variant of the straight barometric principle employs a system similar to the one used in aviation in the rate of climb indicator. It is shown in Fig. 83.

A hard rubber box (E) is provided with a delicate diaphragm (D) made from a thin rubber membrane. One side of the box connectis to an air reservoir (A) by tube (C). While the rocket ascends the air in the reservoir expands and escapes through a rubber check valve (B). When the rocket begins to fall, the air pressure will increase, and close the valve (B). The denser air will enter the diaphram box through orifice (J). This slight increase of pressure will deflect the rubber membrane to the left, push on the rod (F), and cause the switch blade (G) to contact screw (H).

The barometric pressure scale becomes very small at extreme altitudes, but we need not worry about that at present. At moderate heights one inch of mercury corresponds to about 1000 feet of altitude. The barometric device must therefore be quite sensitive. A reasonable assumption would be a free fall of about one hundred feet before the parachute is released. Too sluggish an instrument would cause the rocket to develop too great a downward velocity, and besides, in case of an impotent rocket, the release might function too near the ground to do any good. The barometric device, therefore, should be able to operate with a pressure differential equal roughly to one inch of water.

In designing the instrument shown in Fig. 83 for the same pressure differential we should really allow one half inch for diaphram displacement, in which case the volume of the air reservoir (A) will be about 760 times the volumetric displacement of the diaphram.

This discussion of release mechanism would be incomplete without mention of an entirely different principle suggested some time ago.

The proposed rocket carries a gyro with its axis of rotation parallel to the rocket axis. The rocket is provided with suitable fins and is so balanced as to turn upside down upon the termination of its ascent. When the rocket turns over, the freely suspended gryoscope will retain its original axis of rotation, an a suitable trigger attached to the gimbal rings can be made to operate the parachute re-

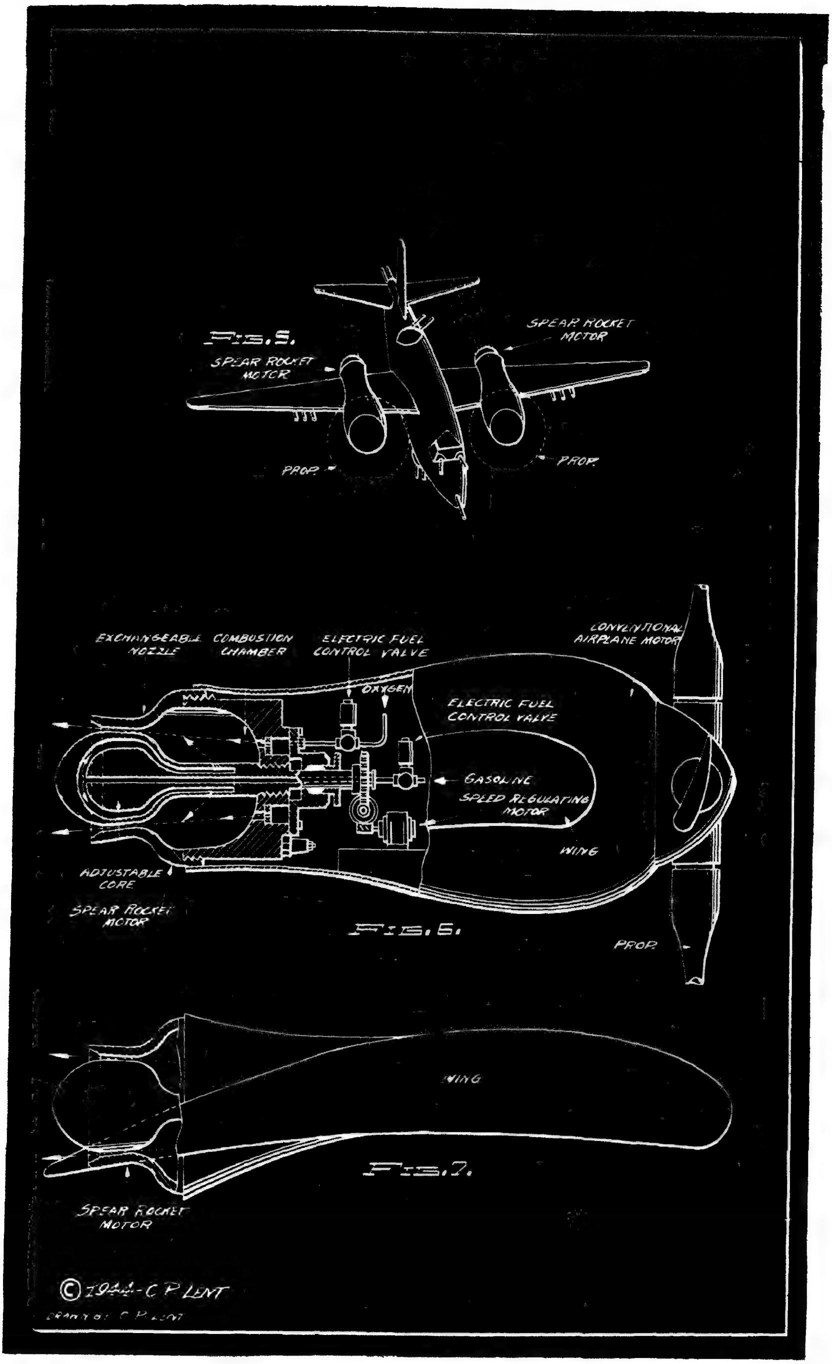


FIG. 5.
SPEAR ROCKET MOTOR
SPEAR ROCKET MOTOR
PROP.
PROP.
EXCHANGEABLE NOZZLE
COMBUSTION CHAMBER
ELECTRIC FUEL CONTROL VALVE
CONVENTIONAL AIRPLANE MOTOR
OXYGEN
ELECTRIC FUEL CONTROL VALVE
GASOLINE
SPEED REGULATING MOTOR
WING
ADJUSTABLE CORE
SPEAR ROCKET MOTOR
FIG. 6.
PROP.
WING
FIG. 7.
SPEAR ROCKET MOTOR
© 1944 - C P LENT
DRAWN BY: C P LENT

FIG. 85

A proposed design for a rocket craft utilizing the spear rocket motor design shown in Fig. 56, page 56, and invented by the writer. The capacity of the motor can be regulated by a pair of electric fuel valves and the discharge orifice of the nozzle can be changed to suit the fuel capacity. The motor can be attached in the back of conventional airplane motors or be a part of the wing proper.

FIG. 87
The jet-propelled flying wing. The air is drawn from forward, is compressed by heating, and is exhausted via rear vents.

lease. It appears that this method could be made to function with entire satisfaction, granting a properly constructed gyroscope. Much more research will be needed to produce a practical commercial weather rocket which can be easily and safely operated and such advanced ideas as illustrated in Figures 85 and 86, which show some advanced thought regarding future rocket transportation possibilities as submitted by the writer.

All who have studied the possibility of jet propulsion for aircraft have agreed that for speeds below 600 M.P.H., and beneath stratospheric levels, this method of motivation cannot compete with the present aircraft engine and propeller combination in efficiency. Analysis reveals that rocket power will come into its own only where other methors start to fall off: at high speeds and high altitudes. Yet, paradoxically, one of the most immediately promising fields for its use is one in which low speed is combined with sea level altitude. Despite its very high fuel consumption in comparison to other engines, the rocket motor could well be utilized for assisting the take off of heavily loaded airplanes.

The outstanding obstacle to higher payloads and longer cruising ranges for modern planes is the limitation imposed by their take-off performances. Wing lift increases roughly as velocity squared and when the loading of a plane is increased its take-off speed will also necessarily rise. The early trans-Atlantic attempts with their long and hazardous ground runs dramatically emphasized the difficulty of getting off the runway with a very heavy load.

The take-off problem has been attacked from two angles; improvements in the plane itself and the application of external power to launch the plane into the air. Development of more efficient airfoil sections has greatly aided performance by creating a higher lift coefficient at a given speed. Numerous experiments with flaps and slots have been conducted to add lift during the ground run, and in some instances have shown promise, particularly the Fowler type extensible flap.

In Fig. 87 it can be seen a design for a jet-propelled flying wing. Such an arrangement might help in boosting the plane at the take off and dispense with the use of large landing fields in the future.

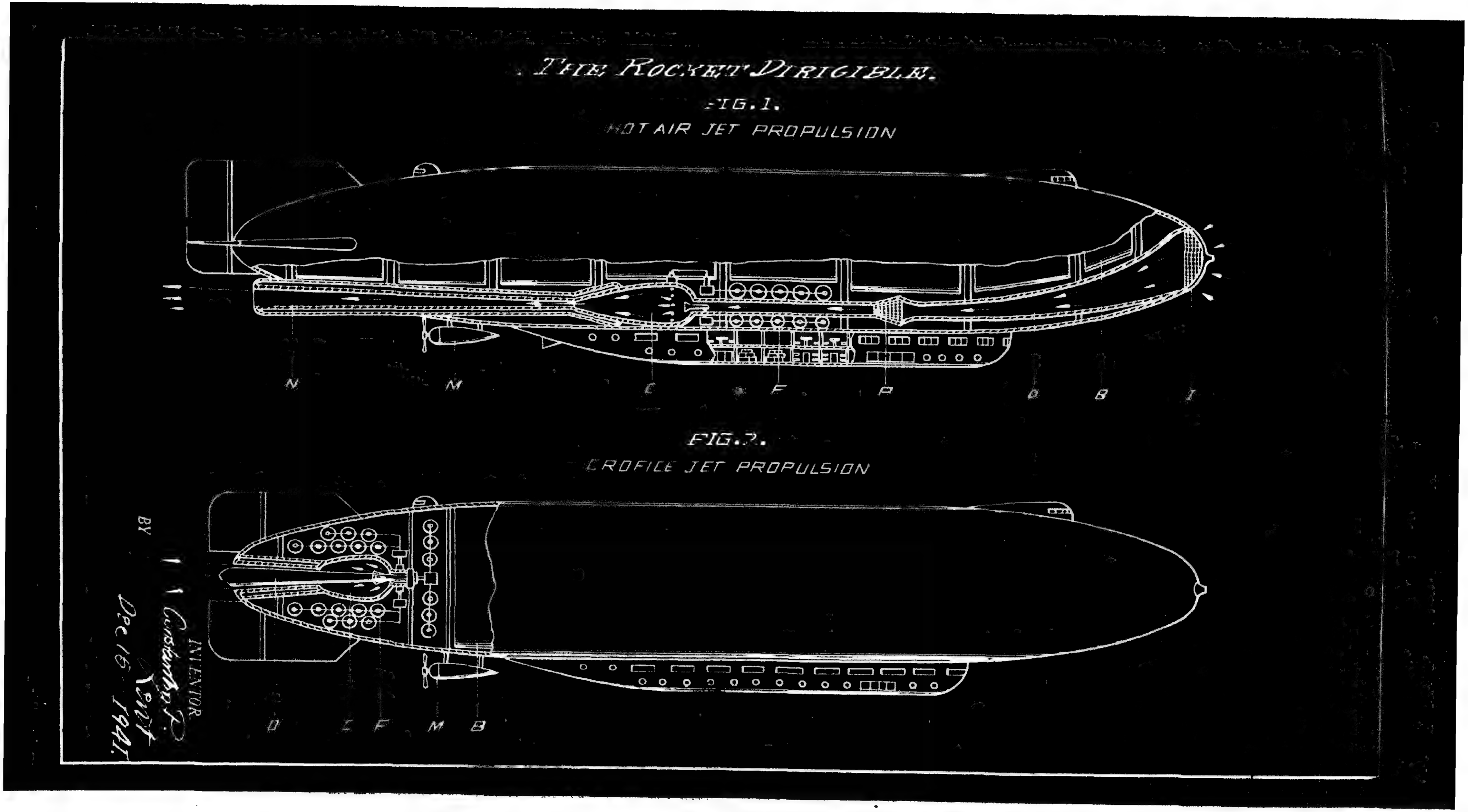
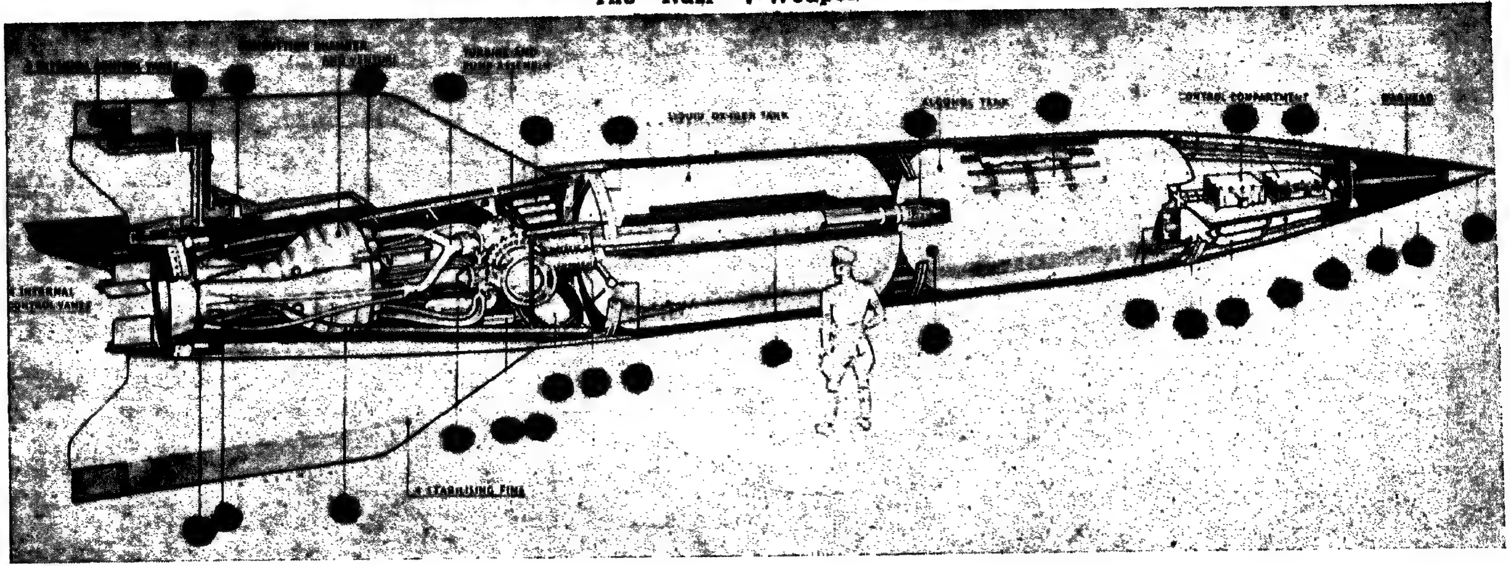

THE ROCKET DIRIGIBLE.
FIG. 1.
HOT AIR JET PROPULSION
N
M
C
F
P
D
B
I
FIG. 2.
ORIFICE JET PROPULSION
D
E
F
M
B
INVENTOR
Constantin P. Rent
BY
Dec 16 1941.

FIG. 86

A suggestion for a jet-propelled lighter-than-aircraft. Two possible ways; the hot air jet-propulsion principle can be used or the writer's own, *the orifice jet-propulsion principle.*

The Nazi V-Weapon


4 EXTERNAL CONTROL VANES
COMBUSTION CHAMBER AND VENTURI
TURBINE AND PUMP ASSEMBLY
LIQUID OXYGEN TANK
ALCOHOL TANK
CONTROL COMPARTMENT
WARHEAD
4 INTERNAL CONTROL VANES
4 STABILISING FINS

Key to Diagram

1. Chain drive to external control vanes.
2. Electric motor.
3. Burner cups.
4. Alcohol supply from pump.
5. Air bottles.
6. Rear joint ring and strong point for transport.
7. Servo-operated alcohol outlet valve.
8. Rocket shell construction.
9. Radio equipment.
10. Pipe leading from alcohol tank to warhead.
11. Nose probably fitted with nose switch, or other device for operating warhead fuse.
12. Conduit carrying wires to nose of warhead.
13. Central exploder tube.
14. Electric fuse for warhead.
15. Plywood frame.
16. Nitrogen bottles.
17. Front joint ring and strong point for transport.
18. Pitch and azimuth gyros.
19. Alcohol filling point.
20. Double walled alcohol delivery pipe to pump.
21. Oxygen filling point.
22. Concertina connections.
23. Hydrogen peroxide tank.
24. Tubular frame holding turbine and pump assembly.
25. Permanganate tank (gas generator unit behind this tank).
26. Oxygen distributor from pump.
27. Alcohol pipes for subsidiary cooling.
28. Alcohol inlet to double wall.
29. Electro-hydraulic servo motors.

PRACTICAL HINTS TO EXPERIMENTERS

Those who have not personally experienced the handling of liquid oxygen are not likely to foresee the difficulties that will be encountered, for under field conditions, without the proper equipment, it can sometimes be quite annoying and very uncomfortable. But if the experimenter provides himself with the simple pieces of apparatus described here, it will become an easy operation to charge a rocket tank with liquid oxygen.

It may be well before proceeding with description of the apparatus to mention a few "don'ts" that should be remembered. Don't attempt to tip a Dewar flask of 20 liters or larger, for this will result in damage to the flask. Don't try to transfer liquid oxygen from the flash to the rocket tank with a thermos bottle, for the extreme temperature will shatter the lining of the thermos. Don't forget to remove your wrist watch and rings. If gloves are worn be sure that they are of a size that can be quickly removed. Liquid oxygen held in close contact with the skin by gloves or rings will cause bad burns.

The ordinary commercial Dewar flask consists of an outer case and two spherical containers, one within the other. The center chamber is suspended by a long slender neck, being secured near the top to the outer case. The space between the concentric spheres has a fairly high vacuum while the outer space is at atmospheric pressure. The two spheres are usually made of spun copper. (see Fig. 92)

Noting the suspension of the center chamber one can readily understand why the larger flasks should not be tipped. The liquid should be dispensed with the use of a syphon such as the one illustrated in Fig. 92, using a small hand pump to supply the necessary pressure. This can be constructed very simply by soldering onto a length of half-inch copper tubing a sleeve of the same diameter as the neck opening, providing an inlet for air pressure. A rubber jacket is used as a seal when held in place over the opening. The tubing then being bent to a goose neck shape.

Smaller flasks can be tipped without fear of damage but due to the long slender opening the inner chamber will soon develop a vacuum preventing rapid flow. This can be overcome by inserting a small tube into the neck to the bottom of the flask, bending it down along the outside and fastening it to one of the handles. This will form a sufficient vent to keep the liquid free-flowing into a funnel of the type shown in Fig. 92 right.

The cone and cylinder (Fig. 94) are light gauge sheet copper with soldering seams. Near the junction of cone and cylinder there should be placed a disc of fine copper wire mesh to prevent condensation ice particles from entering the tank. The tubing at the bottom may be made from a length of copper tubing flared at one end and soldered to the cone with the flare on the inside. The size of this tubing should be not less than 3/8" inside diameter and not less than 12" in length. The outer walls of the cone and cylinder are covered with 1/2" of asbestos or spun glass held in place with canvass or other suitable material.

When the experiments require larger quantities the funnel illustrated in Fig. 94 will be found to be more efficient. The body of the funnel, formed from two hemispheres, makes for reducing surface area. The addition of a rubber lid sealing against knife edges and using air pressure to force the liquid from the funnel, makes insulation of the outer surface unnecessary since the liquid will remain for only short periods of time.

In general, the design of rocket tanks follows the rules laid down by good enginering practice as applied to all pressure vessels. However, a rocket tank differs from other pressure vessels in one important respect. The drastic weight economy, imposed by the conditions of the problem, requires us to reduce the safety factors to the very minimum and to adopt the most economical shape for our tanks.

A study of the underlying theory brings out one surprising fact, namely that no matter how large or how small a tank we may build, its cubic capacity per pound of weight of the structure will remain constant, provided other conditions remain the same. There is no scientific basis for the popular impression that we can make the tanks of a large rocket carry more fuel in proportion to their weight than those of a small rocket.

Let us first consider a spherical tank, since a sphere is the most economical shape for a tank that can be adopted. For the purpose of this discussion we shall

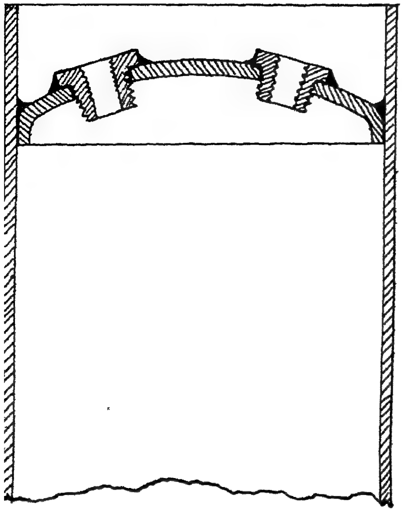


FIG. 88

A simple and practical way to attach covers to cylinders is shown above. The cover is shoved about one inch below the end of the cylinder and then it is silver soldered.

assume a seamless sheet metal sphere without fittings.

Let:

V=capacity of the tank in cubic inches.

R=radius of the tank in inches.

P=internal pressure (pounds per sq. in.).

F=stress in the metal (pounds per sq. in.).

D=the density of the metal (pounds per cubic inch).

W=the weight of the tank in pounds.

H=the weight of the vertical wall in a cylindrical tank.

We know from a study of the strength of materials that the required wall thickness in a spherical shell subjected to internal pressure is:

Now the capacity of the tank is equal to the volume of the sphere:

$V = (4/3)\ \pi R^3$

therefore, $R^3 = (3V)/(4\pi)$

and the surface of the sphere

will be $= 4\pi R^2$

then $W = 4\pi R^2 tD$

or $W = (2\pi R^3 PD)/F$

(substituting for

or, substituting for R:

$$W = V\ 1.5\left(\frac{PD}{F}\right)$$

which shows that the weight of the tank is a linear function of the volume, all the figures within the brackets remaining constant for a given set of working conditions. In other words the weight-capacity ratio of spherical tanks is a constant regardless of size.

Now a spherical tank is not an easy one to build, nor a convenient one to handle. In practice cylindrical tanks are generally used. The ends of such tanks are commonly dished, or given the form of a portion of a sphere with the radius of curvature equal to the diameter of the cylinder. When that is done, the tension in the metal is the same in the end plates as in the walls of the cylinder, and metal of the same thickness may be used throughout. This is very desirable, since it economizes on the material and does away with the ned of staybolts.

The weight per volume of a cylindrical tank will depend on its shape, or rather upon the H/R ratio.

We can vary this ratio at will from zero to infinity, although in practical tanks this ratio would fall between 2 and 10, with, say, 5 as a fair average condition

The weight of any tank can be calculated by the following equation:

$$W = \frac{(VPD)}{(\ F\ )} \quad \text{(Form Factor)}$$

The form factors for cylindrical tanks with dished heads with a radius of curvature equal to the diameter of the cylinder are given in a table below. The reader can easily check the derivation of the formula, and form factors, by a method of reasoning analogous to that used for spherical tanks.

H/R ratio	Form Factor
0	7.8
2	2.7
5	2.3
10	2.15
Infinity	2.0

snug fit with the tube which forms the cylindrical part of the tank. The fittings are first silver soldered into the end plates, and then the end plates are in turn silver soldered to the tank. Soft solder (lead-tin alloy) has not sufficient strength for high pressure work, and should never be used in tank construction.

Whatever the material decided upon, our selection should be governed by commercially available shapes and sizes. A piece of seamless tubing should be used for the body of the tank, since forming it out of sheet metal introduces a longitudinal seam which is very undesirable.

Some consideration should be given to the method of attaching the tanks to each other and to the rest of the rocket structure. This will of course depend upon the design of the particular rocket being built. One method is to make the end plates fit inside the tank and about one inch below the ends of the cylinder, (Fig. 88) so that the projecting rims make a convenient place for connections. Otherwise lugs or other projections, welded to the tanks, may be made to serve the same purpose. (Fig. 89). In some cases, as in two-stick "Repulsor" type of rockets, the tanks are merely held together by clamps or metal bands.

The fittings in the case of brass or copper tanks are brass I.P.S. reducing bushings of the requisite size, silver-soldered into the tank ends. In case of aluminum tanks the same procedure is used, except that aluminum fittings are welded into the cover. The fuel tank will require two fittings, namely, one for the feed tube and one for the filling hole.

In rockets of 1/2 inch nozzle throat diameter both of these may be of 1/8 inch pipe size, so that 1/8 by 1/4 inch bushings should be used.

A Schrader tire valve, provided with a pipe thread at its base is used as a plug for the filling hole, and also serves as a check valve for applying the nitrogen pressure to the tank. It may be well to point out in this connection that a specially constructed hand operated needle valve would perhaps be preferable to a tire valve, especially when pressures much above 350 pounds per sq. inch are to be used.

The fittings on the oxygen tank are the same except that it is well to use larger sizes throughout. Liquid oxygen tends to boil vigorously and to flash into vapor upon contact with any surface at room temperature, so that considerable diffi-

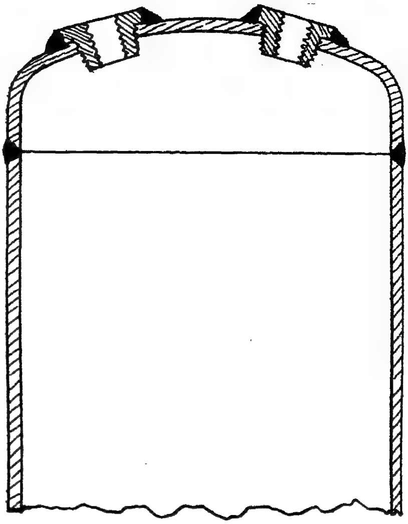


FIG. 89

Another simple way of securing covers to fuel cylinders. The cover is of the same diameter with the cylinder and is silver soldered to the former at the seam.

This offers a very useful method for making preliminary calculations in rocket design, since we do not have to know the physical dimensions of a tank to estimate its weight. A large number of possible designs may be checked without the loss of time required by the ordinary methods. It is understood, of course, thatthese formulas neglect such details as fittings, seams, etc.

Rocket tanks have been made of various materials such as aluminum, brass, copper, or steel, depending on conditions and the designer's fancy.

In general, aluminum alloys are preferable to other materials, because lighter tanks may be made from commercially available alloys. On the other hand the welding of aluminum requires the services of skilled professional welders to be executed properly. Where these are not to be had, it may be necessary to use copper or brass tanks, which will somewhat increase the weight of the rocket, but will certainly facilitate the construction work.

The end plates are shaped with a hammer over a stake, the edges are turned down to form a lip, which should make a

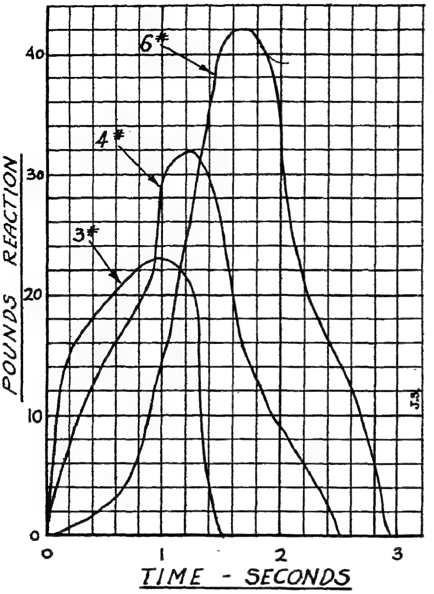


FIG. 90

Thrust curves for powder charges, in pounds reactions and time-seconds. See text for explanatory notes.

culty is always experienced in filling an oxygen tank. The filling hole should be no smaller than 3/8 inch pipe thread. A safety valve is made to screw directly into this hole. A vast hole with a valve should also be provided, to serve as a vent while the safety valve is being screwed home, otherwise it is very difficult to catch the thread against the pressure developed by the boiling oxygen.

As a safety measure, all tanks should be tested after completion, in order to guard against disastrous explosions. To test a tank it should be filled with water, and the pressure should be applied by means of a hydraulic pump. A tank in order to be safe should be able to sustain one and a half times the contemplated working pressure without leaks or any serious bulging of the walls. It is always advisable, though not absolutely necessary, to make up a short sample tank of the same tubing from which the regular tanks are to be made. This small tank can then be tested to destruction to determine its ultimate strength. In conducting such a test it will be found that as the pump is worked, the pressure rises steadily up to a certain point, namely the yield point of the material. When that is reached, the pressure will not rise any more as the pump is worked, but the walls of the tank continue to expand at a constant pressure. Finally the tank will burst at some point, which will be indicated by a spray of water.

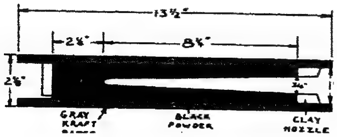


FIG. 91

A cross-section of a "6-lb." rocket charge. The tube is made of paper and the nozzle of clay, the charge is black powder.

The idea of slowing the descent of a falling body, by means of a cloth canopy, is centuries old. Shrangely enough one of the first uses to which it was put was in lowering empty rockets and suspending pyrotechnics in the air. Long before the first Montgolfier balloon rose from the earth, men skilled in the preparation of spectacular fireworks were using small chutes to hang blazing displays in the night skies. Old records tell of sending small animals aloft in rockets and their safe return to earth by 'chute.

At the opening of the 20th Century, Maul of Germany and Antoonivich of Russia were granted patents on parachutes designed to lower empty rocket shells. During the World War the parachute really came into its own. For not only were many lives saved in the air, but millions of small 'chutes were used in conjunction with magnesium flames, "flaming onions", star shells and other devices, many of which were shot skyward by rockets.

Goddard may be credited with the first application of the device to a liquid fuel rocket. On his shot of July 17, 1929, a 'chute lowered the rocket, containing a barometer and camera, unharmed. Since then he is said to have perfected his method of ejection to the point where it functions "unfailingly". During 1927, 1928, 1929 several Germans demonstrated powder rockets equipped with 'chutes. The G.R.S. claim to have installed them in their later "Repulsors", and Winkler had one in his large liquid fuel rocket which exploded when shot during 1932.

Parachutes have reached their highest state of efficiency as lifesaving devices, hence a few characteristics of this type may be of interest to those seeking to apply them to rockets. The best 'chutes are made of the highest grade of Japanese "Habauti" silk, imported as yarn and woven here by special processes.

Composition of Black Powder for Rockets

Authority		Saltpetre	Sulphur	Charcoal
Chinese Rockets		57	14	29
Morel		59	14.8	26.2
Bigot		55	14	31
Geisler		56.25	25	18.75
Congreve		62.44	14.38	23.18
Hale-Hooper		66.7	13.3	20
British Mk VII		65	15	20
Faber	A	54	9	36.5
(Modern	B	56.2	12.2	32.8
practice)	C	72.8	13.6	13.5

Summarized Data on Small Rocket Charges

Manufacturer's designation	3 lb.	4 lb.	6 lb.
Actual wt. of charge, lbs.	.6875	.9375	1.5
Powder content wt., lbs.	.250	.406	.6875
Maximum reaction, lbs.	23	32	42
Average reaction, lbs.	15.5	15	17.1
Duration of reaction, sec.	1.5	2.5	2.8
Average jet flow, lbs/sec.	.167	.1624	.246
Average jet velocity, ft/sec.	2980	2970	2230
Input: Output ratio, lbs/sec.	92	92	69

Congreve Rockets

Wt. of Rocket	Load	Estimated Range ft.	Elevation Optimum
42 lbs.	12 to 18 lbs. incendiary material	3500	60°
42 lbs.	12 lb. explosive shell	3500	60°
32 lbs.	18 lbs. incendiary material	2000	60°
32 lbs.	12 lbs. incendiary material	2500	55-60°
32 lbs.	8 lbs. incendiary material	3000	55°
32 lbs.	12 lb. explosive shell	2500	55°
32 lbs.	9 lb. explosive shell	3000	50°
32 lbs.	5 lb. explosive shell	8000	55°
32 lbs.	200 carbine balls	2500	55°
32 lbs.	100 carbine balls	3000	50°
12 lbs.	72 carbine balls	2000	45°
12 lbs.	48 carbine balls	2500	45°
9 lbs.	Hand grenade	2000	45°

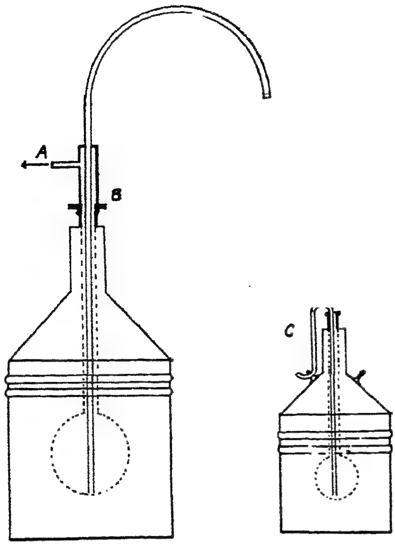


FIG. 92

Two methods of syphoning liquid oxygen. (A) is a lead to air supply; (B) is a rubber gasket, and (C) the inlet for a small Dewar flask.

Its weight is about 1.45 ounces per square yard. Recently pongee silk has appeared as a competitor as it is much less expensive and but slightly inferior in quality. Either silk must meet Department of Commerce specifications for 'chutes; filing 90 and warp 120, double threads, tensile strength of filing 50 pounds, of warp 40 pounds. Tear resistance 6 pounds across filing, 4 pounds across warp. (Warp is vertical, filing horizontal.)

FIG. 93

A photograph showing the manner in which rockets are placed on guide rails under the wings of the Bristol Beaufighter. The rocket is made up of a shell tube with an explosive head, with a cordite propelling charge ignited by the pilot by a platinum fusee wire. The rockets are stabilized by four fins in the tail.

The silk is sewn together in triangular patches to form a large circular canopy, at the top of which a round vent is left open to prevent bursting of the 'chute when rapidly opened; also allowing the trapped air to escape, reducing swinging. The shroud lines, of silk cord, run up one side of the dome and down the other, usually being 12 in number, but giving the appearance of 24 lines from the skirt down. The number may be reduced for smaller 'chutes.

An average 'chute is 24 feet in diameter, giving a man weighing 175 pounds a rate of descent of 16 to 18 feet per second. Empirical figures which may be applied to rocket 'chutes are:

Sq. ft. of silk per lb. of load	Drop per second in feet
3	14
4	10
5	8

It must be borne in mind that while slow descent is desirable, the slower the descent the greater the wind drift.

When a jumper jerks the ripcord, rubber strands pull back the flaps of the canvas pack, allowing the spring-loaded pilot 'chute, usually 30 inches in diameter, to pop out and drag the main 'chute after it. Complete opening is accomplished from 1½ to 3 seconds after the ripcord is pulled. The pilot 'chute is not being used in the latest models, but will undoubtedly be of use in rocket installations. Small 'chutes of the type used by the Navy to drop flares and messages are available for a few dollars each and would probably be suitable for present experimental work.

When not in use 'chutes should be loosely rolled and stored in a clean, dry place. Unrolling and airing once monthly will prevent moding and deterioration of the silk. If the silk becomes spotted with dirt or grease, do not wash, but clean with a non-injurious solvent.

When preparing for use stretch 'chute out on a clean table, separate lines into two groups and hold down at one end of table. Straighten out panels until 'chute lies in flat triangular shape. Fold both longitudinal edges in to the center, then from the skirt, fold endwise, fold on fold, until a small flat bundle is made. Fold up shroud lines, avoiding tangles. Do

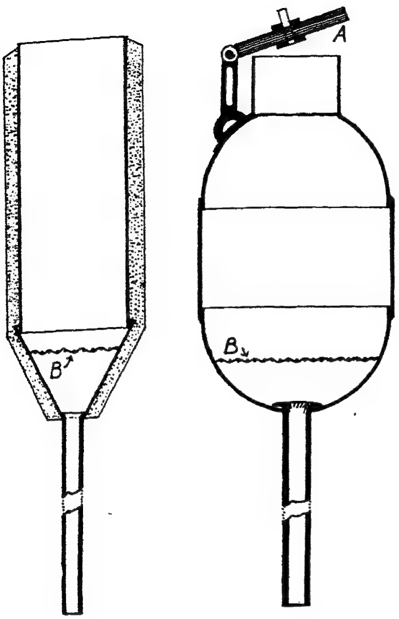


FIG. 94

Two types of oxygen funnels. The one on the left has an insulating heat covering.

not roll up the 'chute, or wind the lines around it, as this will delay and may prevent opening.

Despite the fact that the liquid fuel rocket is the logical choice for aerological research, the dry fuel or powder rocket still retains a sphere of usefulness. Because of its cheapness and simplicity it is an excellent means of testing various shaped hulls for performance under rocket power, determining stability of design, for solving fin problems, testing locations of gravity in relation to other centers and invaluable in training members in launching rack technique, timing, photography and the innumerable details incident to a well executed rocket shot. Much can be learned from these powder rocket shots, yet it is wise to keep in mind the dissimilarities between liquid and dry fuel rockets to prevent drawing hasty and erroneous conclusions.

At some experiments with dry fuel rockets I have been present to, motive power was supplied by charges of three sizes, the "s lb." size, the "4 lb." size, and a few "6 lb." size rockets. All rockets were of the standard brand of the Fourth of July type made of black powder.

Fig. 91 is showing a cross-section through a "6 lb." black powder rocket.

The initial step in converting these charges into model propelling units was the precaution of removing the fuse and plugging up the nozzle with a wad of paper. Next the head or garniture, containing the bursting charge, was removed. The stick holder and outer wrapping of colored paper were then peeled off. In an attempt to reduce the weight of the models to a minimum some of the charges were stripped of several of the many layers of cardboard surrounding the compressed powder. The advisability of doing this has not been fully determined, for while three of the models, evidently overstripped, exploded in mid-air, both charges of the successful step-rocket were so prepared, as were those of several other well-performing models. Next and final step was the sealing of the upper ends of the charges with discs of cardboard and strong glue, a process requiring care, for two flights were spoiled by charges firing through the top as well as out the nozzle.

Hulls for the models were prepared with the following materials:

(1) Cardboard mailing tubes of various lengths and diameters. While not streamlined according to current standards, these are easily obtainable and served admirably for simple models. Where necessary the charges were shimmed out to fit the tubing, the bottom of the charge in all cases being flush with the end of the hull. (As the thrust line of the rocket must lie at all times along its longitudinal axis any movement of that axis will produce a corresponding movement of the thrust line, hence there is absolutely no difference in the relative stability of a rocket if the center of propulsion is located above, on or below the center of gravity.) Charges were secured in position within the tubing by metal fin screws or by a balsa block tacked in place above the charge. (See Figures 41 and 43).

(2) Thin dural tubing. One of the sleekest models was constructed by slipping a charge into a length of dural tubing, and securing it by the fin attachment screws. Unfortunately the charge in this model burnt out through the top.

(3) Solid balsa wood. Two blocks of balsa were half-hollowed to snugly accommodate a charge, leaving sufficient solid wood above the hollows from which to construct the head of the model. The halves were glued together under slight pressure and afterward whittled and sandpapered down to the desired form. It

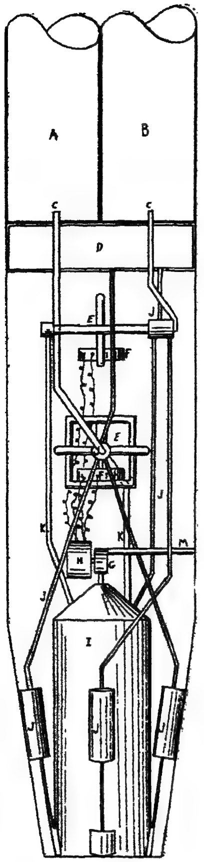


FIG. 95

A proposed design for a fuel and stabilization system for a liquid fuel rocket, using combination gyro-fuel feed.

was found necessary to back the sandpaper with cardboard to prevent following the soft spots in the wood, which tendency creates an uneven appearance. Reducing to plan can be accomplished more easily where a lathe is used to rotate the block, a sheet of sandpaper being held against the spinning wood.

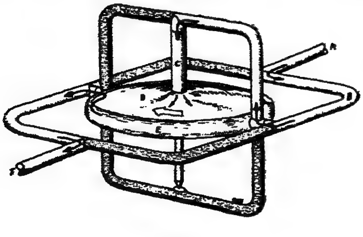


FIG. 96

A proposed design for a centrifugal fuel feed

(4) Built-up balsa. By using laminated former rings around a "6 lb." charge, connecting by stringer strips and covering this frame with thin sheet balsa a model of accepted streamline form was obtained. Fitted with balsa fins and doped to a glossy finish this model promised excellent performance, but alas! its top blew off on the way up.

(5) Sheet dural. The latter made a creditable flight, the former lobbed through the air like a beer bottle out of the bleachers.

Heads for the models in which they were not integral were turned from balsa blocks, in some cases on a lathe, in others by cupping a cone of sandpaper in the palm of the hand and rotating the balsa.

Fins of various sizes and shapes were constructed of:

(1) Thin dural sheet metal—with a right angle flange in which holes were drilled for attachment to hulls by means of screws.

(2) Balsa sheet—glued to balsa or cardboard bodies. Fins of this type must be attached securely in such a position that they will not be burned by the jet flame. They should be gently handled until shot.

After a few seconds of flight the coloring of the rocket becomes indistinguishable, but for appearance's sake and to assist in retrieving the models most of them were daubed with distinctive colors. Cardboard tubing and balsa will take water colors, several coats being necessary for brightness. Metal hulls and fins can be given a high polish by rubbing with steel wool and oil, or many may be painted. Several coats of dope applied over a wood filler, sanded between coats, will give a glossy finish to balsa hulls and heads.

The powder rockets described here are of quite simple construction, purposely so, and their use by beginners in the field of rocketry is recommended to help new experimenters to get acquainted with the behavior of rockets and their use will serve as a basis for the construction of more elaborate models containing landing and recording devices.

With small rockets directional control devices are not needed bu with more efficient rocket motors being developed and the potential range of rockets increasing, it is time to consider some practical remote control devices for the projectiles. This section will deal mainly with methods of radio control, synchronization and apparatus to be used in the rocket itself.

First of all, a method of steering must be decided on. A gyroscopic stabilizing device, controlled remotely, would be one method of steering the rocket, but as this requires a means of spinning the gyro it appears somewhat in the future. Vanes or rudders on the rocket, similar to aircraft controls, might work, but are of questionable value at the anticipated speeds. On smaller rocket models, however, vane control might be practical due to its simplicity and probable lower velocities.

A third method of directing the rocket's course can be obtained by positioning the motor nozzle, the motor being connected to the hull by means of a ball and socket joint. The motor could be swiveled by means of small electrically operated air valves. This is shown in Fig. 64.

A more promising method of steering would be to control the firing of a multi-unit motor. It is known that a motor of one inch nozzle throat will produce a certain force for propelling our projectile. By splitting up this motor into four units, actually four separate motors, the same force would be achieved. With four motors available, we can control the firing of each one individually, thus turning the projectile in any desired direction. (See Fig. 52 right).

Ultra High frequency waves seem best suited for this system of remote control. The carrier or wave can be directed into a beam by mans of a properly designed antenna. We know that waves of this frequency can reach beyond the stratosphere. The simple receiver, whose circuit is shown in Fig. 84, is very efficient for short range work. It is a super-regenerative type using one stage of amplification and a relay control tube which turns on a magnetically operated switch when a signal is received. Naturally, a more sensitive and accurate receiver would be necessary for very remote operation.

Synchronization of the operation of each motor or other piece of equipment in the rocket is most important. One method of accomplishing this is to send a series of timed impulses to the receiver, which are in turn selected by a small commutator. The commutator is synchronized by an oscillator which is controlled from the transmitter. Each time the impulses desired are sent out, an oscillator in the receiver, and one in the transmitter, are allowed to oscillate at the same frequency for the period of one control impulse cycle. This may be used to control any motor, or combination of motors for steering purposes. An oscillogram of the signal pattern and frequency is shown in Fig. 2, of Fig. 84.

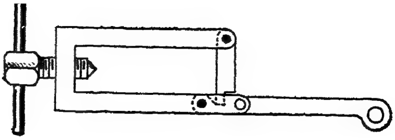


FIG. 97

A very simple instant trigger release used in opening fuel valves. The release cord is attached to the end loop of the longer arm while the seat of the valve is held down. By pulling upon the longer arm the ratchet finger is disengaged and the clamp falls off the valve.

Seven impulses seem to be enough control channels for present purposes, alloting an impulse for each of the four units of the motor and leaving three for other operations, such as parachute opening, etc. The most practical system of selecting these impulses and placing them in their proper relation is through the use of the commutator mentioned before. This could be driven by a spring-wound motor and clutched in synchronism by a small electro-magnet, which is controlled by the oscillator in the receiver.

Another type of synchronizing mechanism, simpler but not as accurate, is one in which relays are used, with the same system of impulsing. The relays are started by a break impulse, which controls the first relay. This, in turn, controls each following relay of which there are seven, one for each control circuit. The complete circuit, with necessary control contacts and other accessories, is shown in Fig. 2 of Fig. 84. By using this type of selection, an oscillator is not needed, as the pick-up time from one relay to another determines the frequency or synchronization of the circuit.

Now that we have devised a means of getting selected control, some means of controlling the motor position or fuel feed must be used in order to steer the rocket while it is being shot upward. The magnetic valve, shown in Fig. 2 or the vibrating piston valve Fig. 3 would have their place in this operation. (Both illustrated in Fig. 64).

The turbine wheel (A) should have two sets of feeding cups, oxygen feeding in one side to one set of cups and alcohol to the other. The cups should be placed

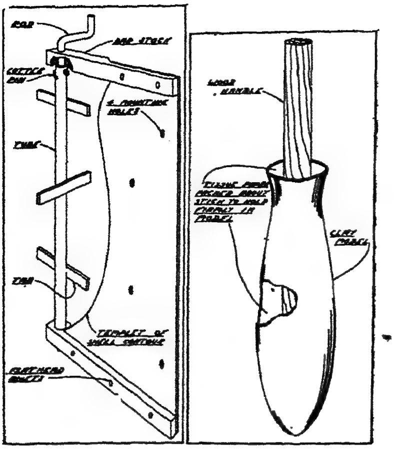


Fig. 98 a
Template for plastic rocket

on the wheel in such a manner as to give the proper mixture. The wheel should be fitted into a well machined casing, with an iron disc of about three times its diameter connected to the wheel. An electro-magnet properly constructed to give maximum magnetic field over the surface of this disc, should be mounted as closely as is practical. The fuel which is fed to this wheel under pressure will cause it to revolve at high speed. A current is now applied to the magnet, generating a field about the iron disc, this causing a braking action of the amount desired, according to the current supplied to the coil. This should give us a very positive control of the fuel supply.

Mixing should be greatly improved by this method for both fuels instead of being fed separately, are squirted immediately into the firing chamber, with greater rapidity of combining achieved. The cups on the turbine can be placed in alternating positions giving a proper fuel proportion.

The other type of valve, (Fig. 2, Fig. 64) is the piston type of valve and is possibly more familiar. If this valve were electrically vibrated and the speed of its vibration controlled very good results could be obtained. This mechanism would also be practical in controlling the air pistons suggested in the third method of steering. Valves of this type are well suited to test stand work and remote firing of the rocket, as well as the above-mentioned use.

Transmission of these control signals by a small radio transmitter of approximately fifty watts of antenna power using a good beam antenna would be most practical for short range operation. The synchronizing mechanism would, of course, be identical to that in the receiver to insure proper impulsing.

These methods of synchronization have been thoroughly tested and found quite practical.

As to constructing the shells of the rockets out of plastic materials the method herein proposed describes a process for making rocket shells which involves a minimum expenditure of money and very little equipment. It can be applied to an yrocket design and produces a product having excellent qualities of hardness, tensile strength, elasticity, and density., The fabrication of compuicated shapes involving under-cuts and inconvenient fineness ratios is relatively simple with this method.

There may be several plastics adaptable to this process, but the one chosen was methyl methacrylate polymer, which is a form of "Lucite". This material was purchased in the form known as "Clear Methacrylate", a liquid sold by Du Pont at about $2.60 a gallon. Two quarts are needed to build a shell which measures needed to build the first shell for the California Rocket Society, which measures eleven inches long by three inches in diameter. Two quarts of solvent, ethyl acetate (at about $1.60 a gallond), are used to thin the ethacrylate. Although there are other and cheaper solvents, ethyl acetate is excellent because of its fast drying quality.

The first step in the construction of a shell is to determine its dimensions from the size and position of the apparatus which it is to house. From these a model is made of any suitable material (wood, wax, plaster, etc.) and of any shape the designer wishes to apply. Because of a shrinkage of 3/4" to the foot in this process, the design should be correspondingly larger. An experimental model was made in the following simple manner.

The Template. A metal template is made of half the shape along its longitudinal axis, including a flare at the base to serve in the model as a handle. The template attached to a forming device is fastened horizontally to the edge of a bench so that excess plaster, shaved from the model while being turned against the template, will drop away cleanly.

The Plaster Model. A batch of plaster is mixed with water to a thick consistency, and in this are dipped quantities of

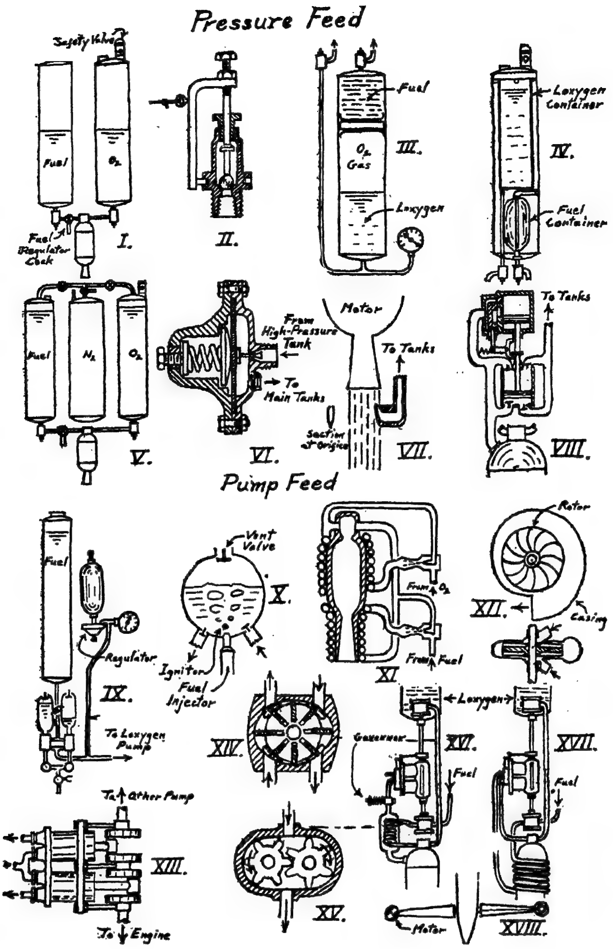

Pressure Feed
Safety Valve
Fuel
O2
Fuel Regulator Cock
I.
II.
Fuel
O2 Gas
III.
Loxygen
Loxygen Container
IV.
Fuel Container
Fuel
N2
O2
V.
From High-Pressure Tank
To Main Tanks
VI.
Motor
To Tanks
Section of Orifice
VII.
To Tanks
VIII.
Pump Feed
Fuel
Regulator
IX.
To Loxygen Pump
Vent Valve
X.
Igniter
Fuel Injector
From O2
From Fuel
XI.
Rotor
XII.
Casing
To Other Pump
XIII.
To Engine
XIV.
XV.
Loxygen
Governor
XVI.
Fuel
XVII.
Fuel
Motor
XVIII.

FIG. 98

A number of suggestions for pressure fuel feeds. Some of the above design have been tested but others have not gone beyond the experimental stage.

manilla fibre, or rags torn into strips. These are wound about the tube in the template to fill out the shape roughly. To this, as the plaster thickens, the rest of the batch is added until the shape of the rocket is defined as the tube is rotated. Grease smeared on the template will keep the plaster from sticking to it. The rod is withdrawn when the plaster is set, and the model removed to dry thoroughly. After drying, it is shellacked and greased for making the plaster mold.

The Plaster Mold. A two piece mold cut by a plane through the longitudinal axis will be satisfactory. The model is set in clay, or modelling wax on its side, and buried up to the cutting plane. A wall of clay, or modelling wax, is built cover the exposed half of the plaster model to a depth of at least one inch. This half of the mold, when set, is inverted and the clay or modelling wax removed. The side of the mold along the cutting plane is notched and the mold left to dry. When dry the exposed sides of the mold and model are greased, a new wall of clay or modelling wax added, and a fresh mix of plaster and water poured. The mold is left to set, and when set, grooves are cut for tying strings. The mold is tied around the model and set aside to dry slowly. This will take about two days (an oven of low heat may be used to hasten this part of the process.) The model is now removed from the mold, irregularities scraped off and air holes filled with plaster (which is then allowed to set).

The Clay Model. Obtain a quantity (several pounds) of modelling clay, dry powdered or moist, and mix with water to the consistency of a thick cream. About three quarts will be needed. Strain this clay mixture through a 70 mesh brass wire screen.

At this point the inside of the mold may be wet slightly. Then hold the mold upright with its open end up, and pour the clay mixture, tilting the mold in different directions to allow the clay to wet the sides and to prevent the clay mixture from splashing. Pour until the mold is filled up to the top and stand the mold on end. Keep adding the mixture as its water is absorbed by the mold. From time to time check the wall thickness of the dense clay next to the plaster by scraping away the excess on top of the mold. When this thickness attains from 3/16" to 1/4" this will vary with the model size) pour out the rest of the mixture and leave the clay treated mold to dry in its upright position. This drying process may be speeded up by inserting a small tubular electric lamp after the clay has stood for at least an hour.

When the clay model is dry it may be removed from the mold. Exercise care in handling because this model is fragile. Use sandpaper to remove seam lines, and fill in air holes with the clay mixture.

Equipment for Dipping. Obtain a piece of wood about ¾" square, or raound, and about six inches longer than the model. Drill a hole in one end, drive a nail through the wood at about three inches from this hole, push in several thumb tacks along the length of the stick and insert the other end in the clay model after a wad of tissue paper to protect the caly. Pack more tissue paper around the stick and thumb tacks in the model until the stick feels secure.

Drill a hole big enough to receive the stick in another piece of wood, and mount this in a vise or other convenient fixture. Drive a nail into the edge of a work bench. The wood is to hold the clay model in an upright position, and the nail to suspend it in an inverted position.

Make a container big enough to dip the clay model completely without danger of touching the sides. This may be done by rolling a cylinder from sheet stock on a bottom or by soldering a used food can, with top and bottom cut out, to another such can having only its top cut out. Fill the container half full of a mixture of one part methacrylate to one part ethyl acetate. From here on use precaution against fire hazard.

The dipping Process. Stand the clay model on the wood in its upright position and paint with a mixture of one part methacrylate to two parts ethyl acetate. Allow about five minutes for this to dry, paint again and allow it to dry a second time. The model is now ready for dipping

Remove the model from the wooden support and dip, inverted, into the can until the liquid rises to the flare. Remove the model from the can and hang it, still inverted from the nail. The excess liquid may be caught in the container or in another can as it drips off. Wipe away the last two or three drops from the apex before they dry. Allow about ten minutes for this coat to dry, or enough time until it feels dry to the touch. Remove the model from the nail and dip again. This time allow the excess liquid to drip back into the can for only two seconds, and then invert the model to upright position, and mount it on the wooden support. The excess liquid on the model should be ample to permit it to run off evenly without leaving drops or streaks on the surface. Again allow about ten minutes for drying. Continue dipping and drying alternately in upright and inverted positions until twenty coats are applied. Once the application of the plastic has been started it should be continued until completed without interruption to avoid cracking. Add more liquid to the can as needed. Work away from all fire to avoid accidents. Bubbles may be removed when dry by applying ethyl acetate. Handle the clay model only by its wooden handle to avoid breakage. Avoid touching the insides of the can with the model dureing the dipping process. Allow the dipped model to dry two days after the last dip before removing the clay.

Fill the model with water after remivong the stick and tissue paper, and allow it to stand overnight. Wash out the clay the next day.

The shell form is now finished, except for trimming and needs no polishing. It may be cut, sawed or drilled whenever necessary. The liquid methacrylate may be used as a cement to secure any attachments.

Additional shells will require about a pint of ethyl acetate each, added to the mixture in the dipping can. These amounts apply only to the small rocket

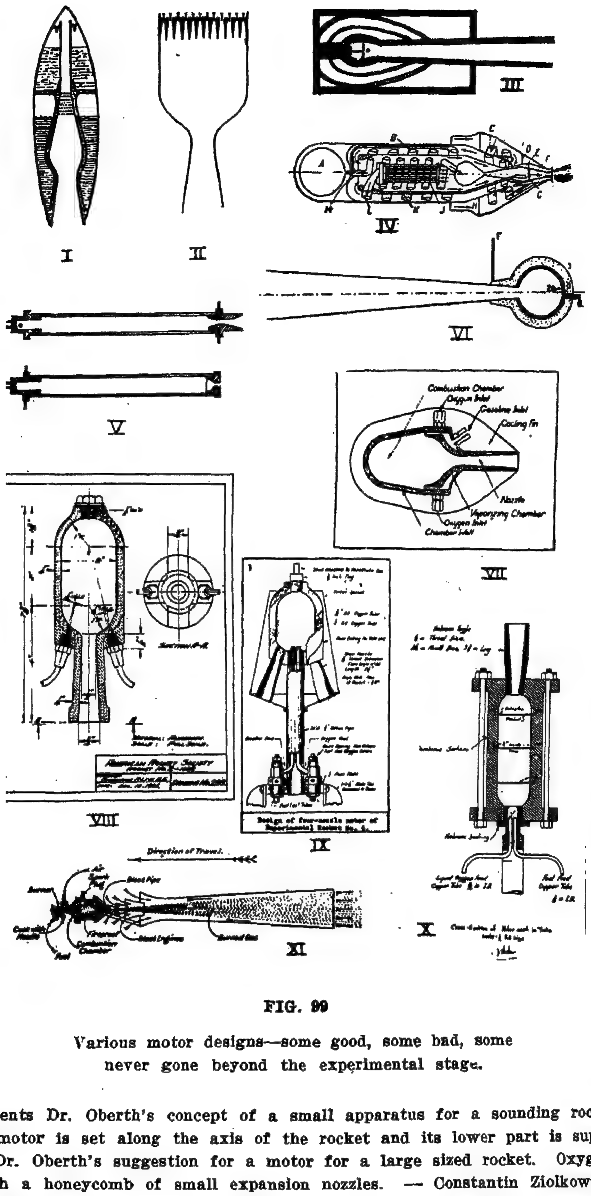

I
II
III
IV
V
VI
Combustion Chamber
Oxygen Inlet
Gasoline Inlet
Cooling Fin
Nozzle
Vaporizing Chamber
Oxygen Inlet
Chamber Wall
VII
American Rocket Society
VIII
Design of four-nozzle motor of Experimental Rocket No. 4.
IX
X
Direction of Travel.
Air
Spark Plug
Burner
Blast Pipe
Cast with Nozzle
Fuel
Fireproof Combustion Chamber
Blast Engines
Burned Gas
XI

FIG. 99

Various motor designs—some good, some bad, some never gone beyond the experimental stage.

Above I, represents Dr. Oberth's concept of a small apparatus for a sounding rocket two or three meters long. The motor is set along the axis of the rocket and its lower part is supported under the fuel tank. II, is Dr. Oberth's suggestion for a motor for a large sized rocket. Oxygen is forced into the chamber through a honeycomb of small expansion nozzles. — Constantin Ziolkowsky, the Russian, suggested the design shown at III. This motor consists of a chamber giving into a long expansion nozzle, the chamber surrounded by two jackets; through the inner the fuel is circulated, through the outer the loxygen. — Federic Zander suggested the idea shown at IV which is a regenerative reaction motor burning atmospheric air which is warmed before entering the motor by the combustion gasses. At V, two designs of Johannes Winkler are shown who favored long slender combustion chambers. Sanders suggested the motor shown at VI which has a spherical combustion chamber and a long expansion nozzle. — For burning gaseous oxygen the motor shown at VII has been suggested. This motor made of tool steel burned close to one hour on gasoline and gaseous oxygen giving a reaction of two pounds and a velocity of ejection of 5400 lbs. — Design shown at VIII is of the American Rocket Society drawn by the writer. This motor is of cast aluminum and at tests it gave splendid results. It delivered a reaction of 60 lbs. in 15 seconds on 1½ lbs. of gasoline. — The motor shown at IX is a multiple nozzle motor also by the A.R.S. — The motor at X is a test motor by the A.R.S. — The design shown at XI was used for atmospheric air as a thrust-augmentor for aircraft.

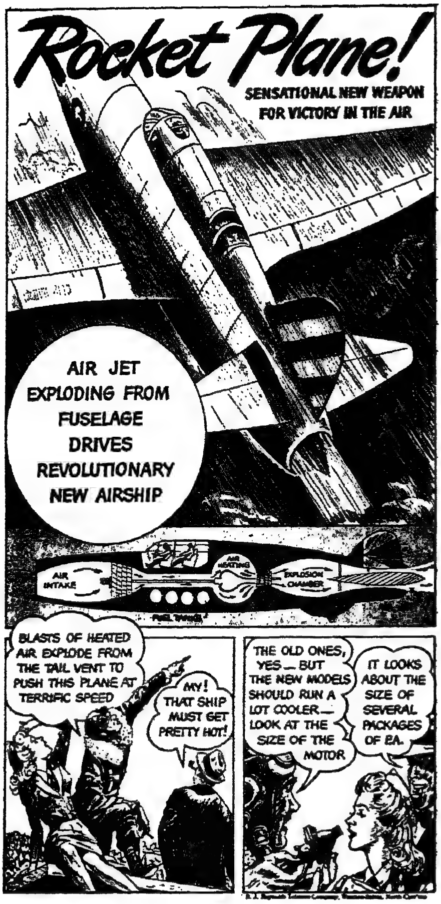

Rocket Plane!
SENSATIONAL NEW WEAPON FOR VICTORY IN THE AIR
AIR JET EXPLODING FROM FUSELAGE DRIVES REVOLUTIONARY NEW AIRSHIP
AIR INTAKE
AIR HEATING
EXPLOSION CHAMBER
FUEL TANKS
BLASTS OF HEATED AIR EXPLODE FROM THE TAIL VENT TO PUSH THIS PLANE AT TERRIFIC SPEED
MY! THAT SHIP MUST GET PRETTY HOT!
THE OLD ONES, YES — BUT THE NEW MODELS SHOULD RUN A LOT COOLER — LOOK AT THE SIZE OF THE MOTOR
IT LOOKS ABOUT THE SIZE OF SEVERAL PACKAGES OF P.A.

FIG. 100

Future has great stores for rocketry but present public interest was capitalized upon by this advertisement of the R. J. Reynolds Tobacco Company, which seems to have confused the Italian Campini plane with a 1932 design of a German rocket motor.

sizes. Larger models naturally require

With an increasing shortage of basic metals, due to defense activities, the use of plastics is becoming a necessity in many fields. Quite aside from the fact that metals are becoming more difficult to obtain "Lucite" tanks have one great advantage over metal tanks. "Lucite" is a crystal-clear hard resin with an approximate tensile strength of 8000 lbs. per sq. in.

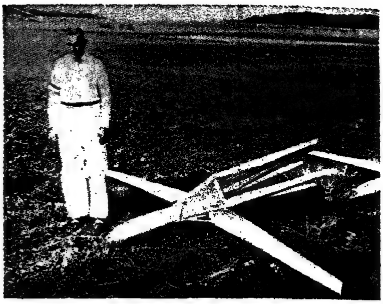


FIG. 100a
A Tilling Rocket

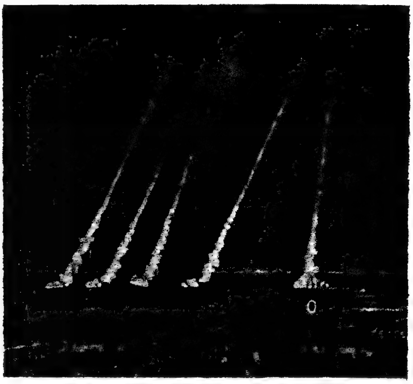


FIG. 100b
German Rockets Zooming Skyward

The transparency of this plastic eliminates the necessity for using measuring devices to determine the consumption of alcohol and liquid oxygen. The change of height of the propellants in the tanks can be readily seen and photographed while a rocket motor is firing on the test stand.

Alcohol will not attack "Lucite" to any extent. It has the peculiar property of increasing its modulus of elasticity when immersed in liquid oxygen. A piece of "Lucite" when thrown on the floor under normal conditions gives a dull ring, after having been immersed and cooled in liquid oxygen it gives a clear pronounced ring similar to that of steel. However, it does not shatter.

As an experimental aid in rocket research this clear plastic will undoubtedly help to simplify test stand designs. Its light weight may help also to make it practical for use in tanks for actual sounding rockets.

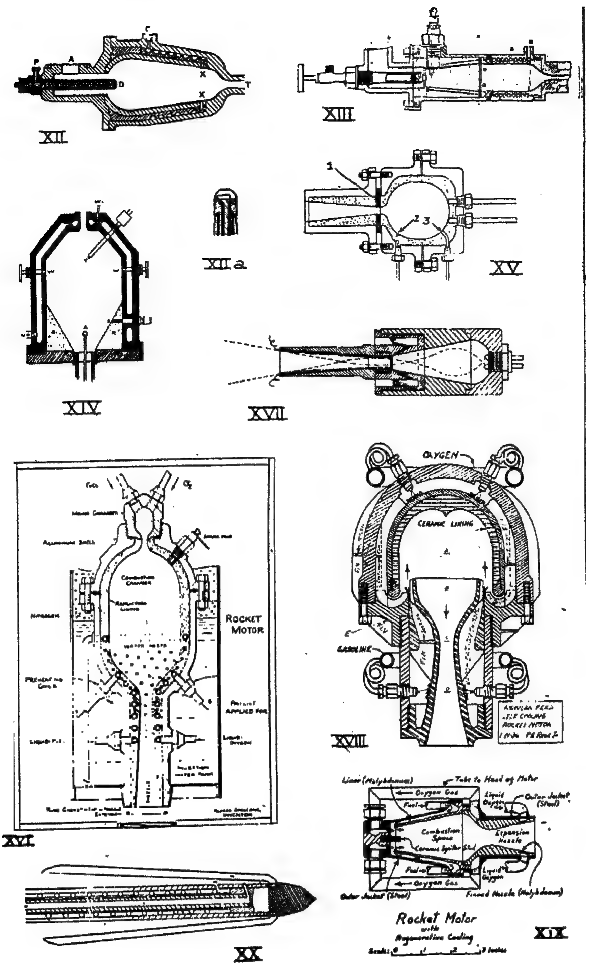
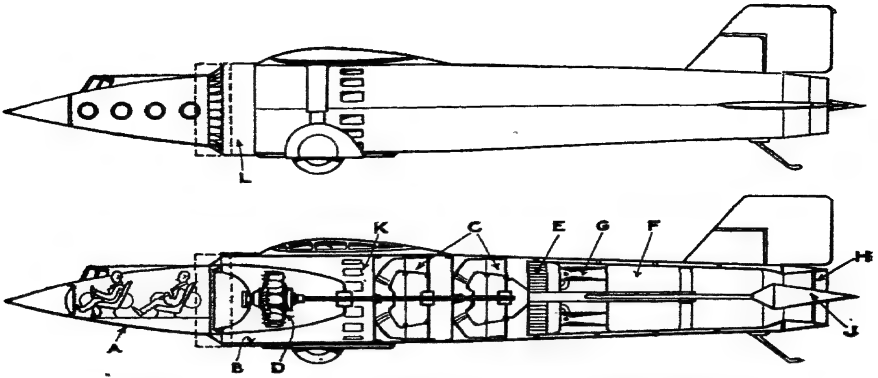

XII
XIII
XII a
XV
XIV
XVII
Rocket Motor
OXYGEN
CERAMIC LINING
GASOLINE
XVI
XVIII
Liner (Molybdenum)
Tube to Head of Motor
Oxygen Gas
Fuel
Liquid Oxygen
Outer Jacket (Steel)
Combustion Space
Expansion Nozzle
Fused Nozzle (Molybdenum)
Rocket Motor with Regenerative Cooling
XIX
XX

FIG. 101

Some more designs of motors and nozzles.

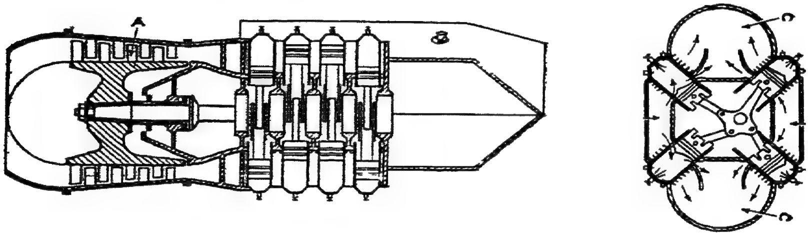
Above XII, is a carborundum lined motor, also the one shown at XIII. Water was circulated around the chamber and tests showed that the temperature of the combustion chamber was 1800 C and the velocity of ejection 4000 feet per second. — At XII is a section through a fuel injector and igniter rod. — At XIV is shown a most successful apparatus used for tests to determine combustion chamber behaviors. — At XV is a test motor to test refractory lining with a resistant metal at the throat of the nozzle to withstand the erosive effect of gases. — The writer suggested the design shown at XVII in which water is drawn by ventury effect into the throat of the nozzle from a reservoir around the base of the nozzle. The water vaporizes and forms a protective steam jacket for the nozzle lining preventing the burning out of the latter. — In the sketch shown at XVI, refractory lining is used to prevent the burning out of the motor plus water cooling. — At XVIII is a regenerative motor of a complex design. — XIX and XX are both novel designs of regenerative motors in which the fuel is preheated before entering the combustion chamber.



A. Ovoid cabin.
B. Enshrouding cylinder.
D. Radial engine.
E. Rectifier-radiator
F. Combustion space.
G. Annular mixing channel.
H. Discharge nozzle.
J. Cone for varying nozzle orifice.
K. Controlled lateral orifices.
L. Slidable shroud ring.

FIG. 102

A Campini design of high-altitude plane designed to operate at either sub- or supersonic speeds The control cabin is pressure charged.



A. Compressor.
B. Air intake passages.
C. Mixing chambers.
D. Discharge nozzles.
E. Supplementary combustion chambers.
F. Supplementary fuel injectors.

FIG. 103

This is a cross-section through a jet reaction plant employing a multi-bank, air-cooled, two-stroke engine to drive the rotary compressor.

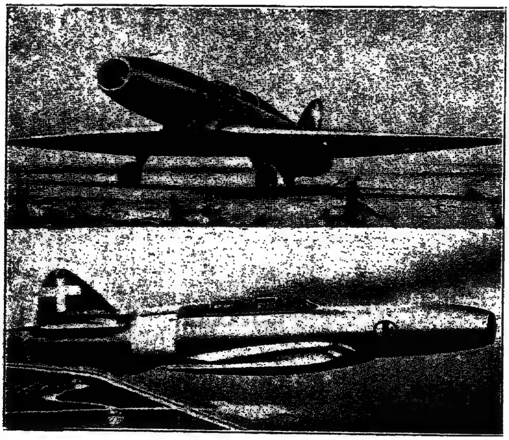


FIG. 104

This remarkable photograph shows the Campini plane illustrated above as it looks from the front and in flight. Note the intake for the air in the nose of the plane and the absence of propellers.

The Hot Air Jet Propulsion Principle

POTENTIAL ADVANTAGES OF HOT AIR JET PROPULSION

The jet re-action principle is not new. As far back as the Alexandrian era, the philosopher, Hero, demonstrated it in his famous aelophile.

The aelophile is reputed to be the first device which could convert steam pressure to cinetic energy. It consisted of a boiler with a pair of pipes leading into two opposite centers of a rotatively mounted spherical body which had two nozzles. The nozzles faced in opposite directions in respect to each other. The steam entering the spherical sphere from the boiler was expelled through the nozzles and the reaction of both jets of steam made the globe turn around. Hero's device was never employed in a practical sense. It was a mere toy used for the amusement of Alexandrian Court.

Around 1680, Sir Isaac Newton produced a vehicle driven by jets. Contemporary prints show it to be a steam boiler mounted on wheels with an elongated steam nozzle facing the rear. The driver, by opening a valve controlling the delivery of steam from the boiler to the nozzle would start or stop the vehicle.

A few years later, a French missionary in China, Father Verbiest, invented a jet propelled wheel which through proper reduction propelled a small carriage.

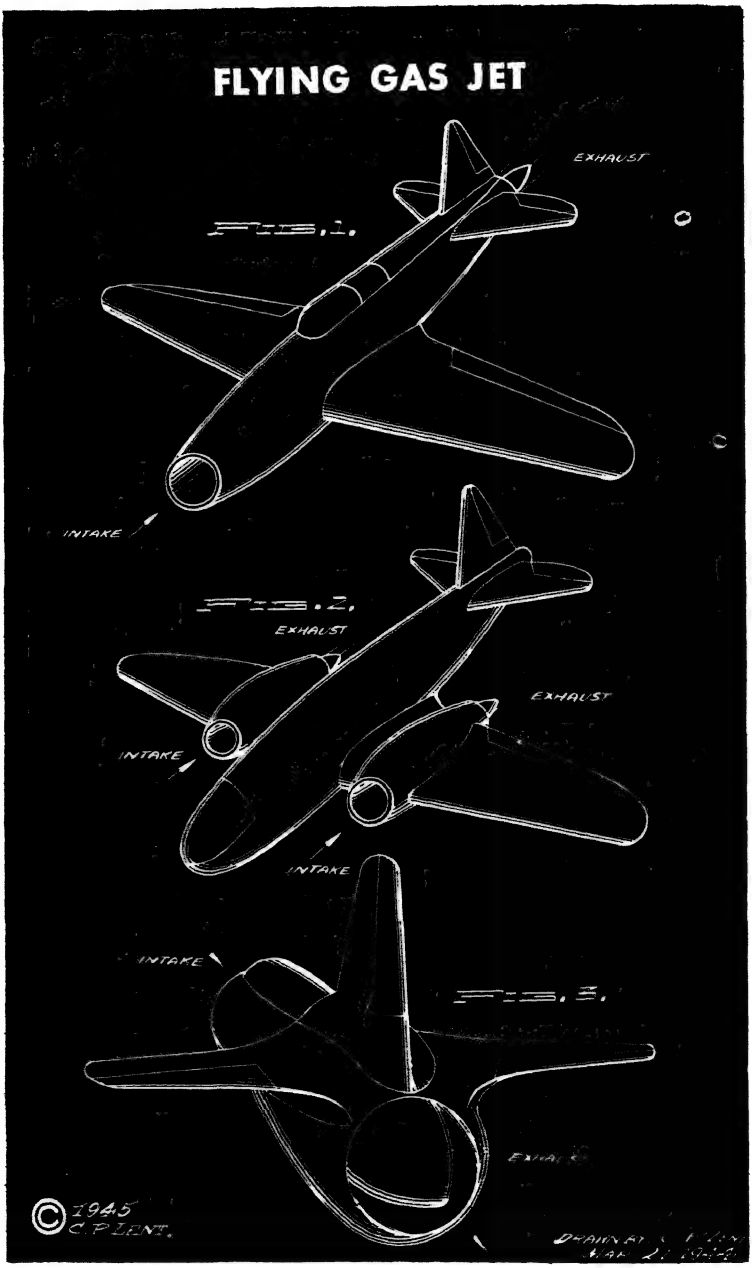
We also know from records of the English Patent Office, that an English scientist, John Barber, was granted a patent on the first gas turbine. That is about all we know of jet propulsion. It did take the invention of the airplane for the jet to find its proper use. And since the first flight of the Wright Brothers in their make-shift airplane forty-two years ago, new design of propulsion are coming into being, employing jet motors.

The present-day airplane is really nothing more than advanced design taken from the original Wright plane. It is larger in size, has greater radius and is generally more efficient. Yet, in operation it is the same, as it depends, life the Wright Brothers' plane, on propellers and on internal combustion engines for its propulsion. Lately, many countries have experimented with a new kind of plane, a closer imitation to birds flying, although more akin to gliding than flying. This is the new hot-air-jet driven craft.

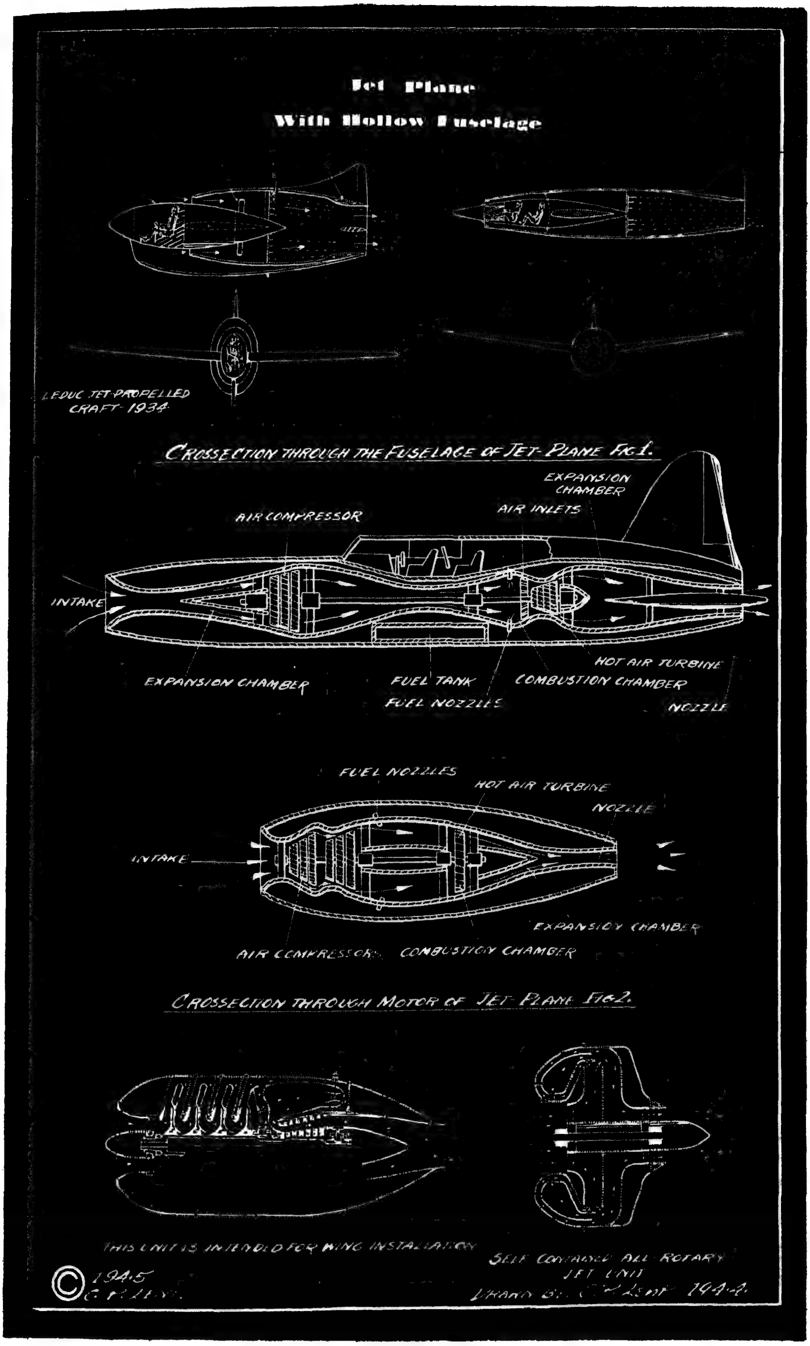
As is well known, the efficiency of the propeller at high speed and in thin air at 50,000 foot altititude is very small. In fact, the higher a propeller driven airplane goes, the efficiency of its propeller and engine diminishes due to the rarity of the air at a high strata. Supercharging the the engine is one answer, but the weight of the supercharging machinery is prohibitive and reduces the payload of the plane.

In the new jet propelled airplane, many of the disadvantages of the propeller and internal combustion engine are eliminated. In addition, it is much easier to operate as all that is required is to throtle down or up the amount of air and gasoline used by the jet to get various speeds. The aircraft is built low to the ground for the simple fact that no ground clearance is needed to accomodate the large radius of the propeller blades. Futhermore, there is no vibration and the jet mechanism weighs much less than the conventional airplane engine; in short, the plane is not front-heavy.

The principle under which a jet engine operates is very simple and in the main the jet motor comprises a streamlined body having a large opening in the front which is the air intake duct and a small opening in the rear which is the nozzle. Right after the intake duct, there are one or more air compressors of special design. The air entering through the intake duct is compressed by the compressor and is injected under


FLYING GAS JET
EXHAUST
FIG. 1.
INTAKE
FIG. 2.
EXHAUST
EXHAUST
INTAKE
INTAKE
INTAKE
FIG. 3.
EXHAUST
© 1945
C. P. LENT.
DRAWN BY C. P. LENT
MAR 21 1944

high degree of compression into the combustion chamber. The combustion chamber is provided with a number of fuel intake nozzles to spray fuel—in this case, gasoline into the highly compressible air. A number of spark plugs initially ignite this mixture of gas and air. The resultant explosion of the mixture produces the forward reaction which drives the device while the gasses are exhausted through the nozzle. The turbine is connected by means of a main shaft to the compressors so that the operation of the exhaust gasses operate the turbine wheel operating the compressors.



Jet Plane
With Hollow Fuselage
LEDUC JET-PROPELLED CRAFT 1934
CROSSECTION THROUGH THE FUSELAGE OF JET-PLANE FIG 1.
EXPANSION CHAMBER
AIR INLETS
AIR COMPRESSOR
INTAKE
HOT AIR TURBINE
EXPANSION CHAMBER
FUEL TANK
COMBUSTION CHAMBER
FUEL NOZZLES
NOZZLE
FUEL NOZZLES
HOT AIR TURBINE
NOZZLE
INTAKE
EXPANSION CHAMBER
AIR COMPRESSOR
COMBUSTION CHAMBER
CROSSECTION THROUGH MOTOR OF JET PLANE FIG 2.
THIS UNIT IS INTENDED FOR WING INSTALLATION
SELF CONTAINED ALL ROTARY JET UNIT
DRAWN BY C. R. LENT 1944
© 1945 C. R. LENT.

One can see at a glance that in a jet engine, air must be sucked in; compressed to a high stage of compression; mixed with gasoline vapors and, lastly, the mixture brought to combustion. The resultant gasses of high speed and temperature are ejecsures are low and therefore a jet motor is built very light. Hence, the power-weight ratio is greatly improved and the craft has higher speed better climbing possibilities.

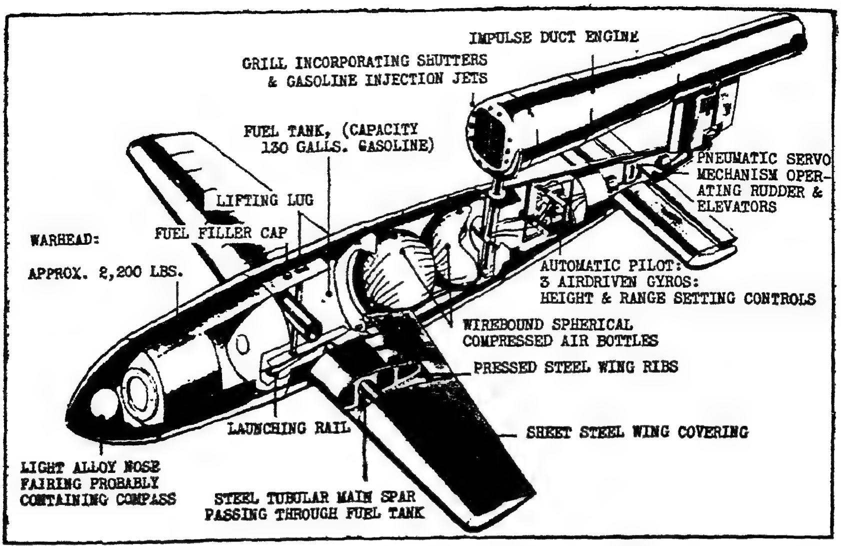

IMPULSE DUCT ENGINE
GRILL INCORPORATING SHUTTERS & GASOLINE INJECTION JETS
FUEL TANK, (CAPACITY 130 GALLS. GASOLINE)
PNEUMATIC SERVO MECHANISM OPERATING RUDDER & ELEVATORS
LIFTING LUG
WARHEAD: APPROX. 2,200 LBS.
FUEL FILLER CAP
AUTOMATIC PILOT: 3 AIRDRIVEN GYROS: HEIGHT & RANGE SETTING CONTROLS
WIREBOUND SPHERICAL COMPRESSED AIR BOTTLES
PRESSED STEEL WING RIBS
LAUNCHING RAIL
SHEET STEEL WING COVERING
LIGHT ALLOY NOSE FAIRING PROBABLY CONTAINING COMPASS
STEEL TUBULAR MAIN SPAR PASSING THROUGH FUEL TANK

FIG. 105 THE ROBOT BOMB — HOW IT WORKS

“The Flying Bomb is maintained in flight by the impact on the atmosphere of a series of explosions at the rear of the propulsion unit. The warhead, which is fitted forward of the fuel tank, contains about 1,800 lbs. of high explosive.

The fuel tank contains approximately 130 gallons of gasoline. Aft of the fuel tank is a compartment which houses two wirebound spherical air bottles which supply air pressure for the fuel feed and automatic pilot.

ted through the nozzle after employing some of their energy for the operation of a turbine wheel, facilitating the compression of the sucked in air. In a jet engine the reaction of the exhaust gasses and the large volume of exhaust both contribute towards the propelling of the engine and plane respectively. In conventional airplane designs a pair of jet motors are used placed on either side of the airplane body. In other designs, the jet engine can be located below or above the body. In large planes, four jet motors can be used placed in pairs on either side of the body. In an early Italian design, the jet engine was located in the central portion of the body, so that the intake duct was located in the nose of the plane.

The drawings show some perspective views of a number of jet driven airplanes of late design and cross-sectional views showing the construction of the jet engines.

Following are some of the advantages of the hot-air-jet propulsion.

(1) In place of the comparatively expensive high octane gasoline or even alcohol, heavy oils, such as parafine, Diesel oils, tar, etc., can be utilized. These fuels are called “safety” fuels as they do not ignite easily, thus preventing fires. At the same time, they can be used without loss of efficiency. Solid fuels, such as powdered coal and certain mixtures of cellulose dust, also have been suggested.

(2) The energy derived from the fuel can be fully utilized as no in-between loss such as resistance of bearings, pistons, shafts, etc., have been overcome. In addition, the use of a transmission and gearing is dispersed with.

(3) The air screw propeller is eliminated, thus increasing the delivery of power output per each single engine. It is a well known fact that the power which may be delivered through a simple propeller is limited. This disadvantage is completely eliminated in a jet motor.

(4 The use of air compressors in a jet engine has the same superiorities similar to tubor-supercharges in the respect of maintaining power at high altitudes.

(5) It has been also suggested that the hot air produced by the jet motor could be used to warm the passenger cabins of the planes in higher altitudes and also prevent icing on the fusilage and the wings of the plane.

(6) The size and weight of the jet motor favorably compares with internal combustion engines and in many cases, it is even several times lighter. All resistance losses of reciprocating parts are reduced and the motor utilizes rotary components exclusively.

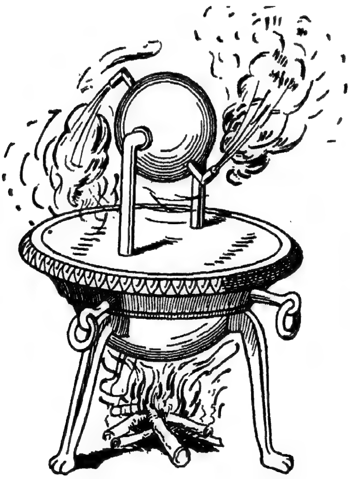
(7) In comparison with internal combustion engines, relative pres-

(8) The elimination of the propeller enables the jet plane to be built low to the ground. Complicated retracting gears can be therefore eliminated and heavy carriages are dispensed with.

(9) The pilot cabin can be located closer to the front of the craft to enlarge the field of vision.

(10) A jet-propelled plane affords lower air-resistance and reduces erodynamic drag due to the fact that the jet engine are completely imbedded in the fusilage of the wings of the plane.

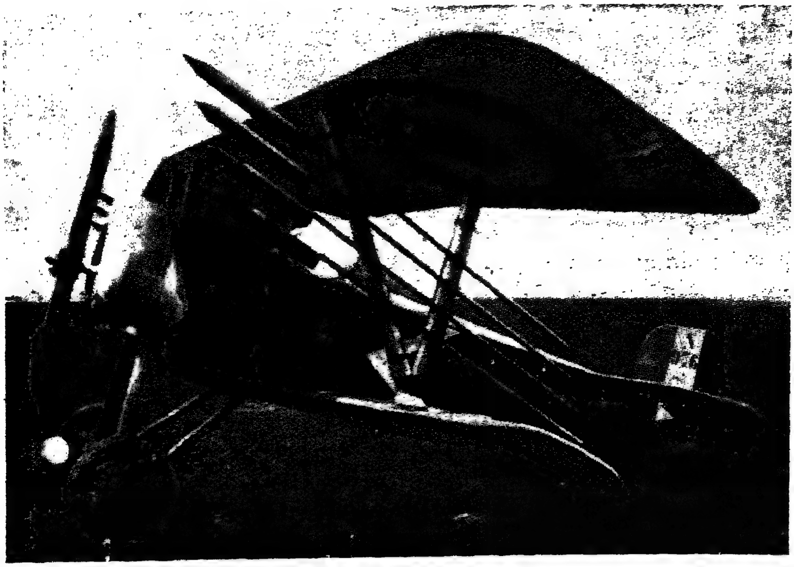
(11) Large aircraft can be equipped with several jet engines which can be operated independently or in groups. Thus, it is possible to cruise with more economy by operating with less than the total number of jet motors.



As far back as the Alexandrian era, the philosopher, Hero, demonstrated it in his famous aelophile.

Hero's device was never employed in a practical sense. It was a mere toy used for the amusement of

ROCKET FIRING BIPLANES



—Ley Photo

French Fuseen Biplane Fitted With Eight Le Prieur Rockets

The forerunners of the rocket discharging planes of the present war were the biplanes of the British, French and Russian aviators which fired jet propelled incendiary projectiles at German captive observation balloons and Zeppelins in World War I. An incendiary missile on piercing the skin of an inflammable hydrogen-filled gasbag was usually sufficient to set it afire. A number of these kite balloons were sent down in flames although it is doubtful if any Zeppelins suffered the same fate.

In addition to the usual single machine gun mounted over the cockpit the armament consisted of large size powder skyrockets attached by their guiding sticks to wing struts or carried in tubes and electrically ignited by the pilot. The rockets were generally mounted in groups of four one above the other on either side of the fuselage. The efficacy of the weapon was poor as the rockets had a low velocity and a range of only several hundred feet.

Lieutenant Y. P. G. Le Prieur, a French naval officer, is credited with suggesting the idea and the rockets usually bore his name. The Nieuport Scout carrying 8 Le Prieur rockets appeared the most popular in this type of warfare.

Little official information was released on rocket armament other than the episode in the spring of 1916, when the flaming rockets of a group of Nieuports set ablaze four enemy balloons.

INDEX and LIST OF PATENTS

PEN-INK
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INDEX

— A —

Page

Abbot, Dr. Smithsonian Institution Report, 1929 5
Accelerometer 74
Acceleration, Catapult 18
Acceleration Rocket 16, 31
Acceleration for Weather Rockets 71
Aerial Cannon 24
Aerological Rocket 73
Aerological Sounding 71
Air-cooling 33
Air Resistance 14
Air Cooling, Motor 21
Alcohol 13, 14
Alloys for Rocket Motors 43
American Rocket Society 9, 19, 21
Altitude Rockets 57, 76, 77
Anti-Aircraft Rockets 16, 22, 23
Antony Fokker 24
Anti-Stuka Gun by Author 16
Asbestos Lining for Tanks 35
Atlantic 18
Aspiring Effect 30
Atmosphere 2, 71
Astronomical 74
Austrians 2
Auborn, Mass. — Dr. Goddard's experiments, 1929 4
Autogyro 80

— B —

Back Pressure 11
Bakelite for Tanks 46
Balloon 74
Balsa Wood 33, 34, 90, 92
Baltic Rocket, by Prof. Oberth 13
Bazooka, American 16
Barograph 73
Barometric Device for Rockets 82
Belgium 25
Benzol 14
Berylium 41, 43
Bjerknes, Dr. 74
British 24, 26
British, Navy Rockets 16
Bomb Colorimeter 10
Boule's Law 41
Boulogne, Attacked by Rockets 1806 1
Boxer, Colonel, Introduces Tandem Rocket 1855 2

— C —

Cameras 74
Cartridge Fuel Feed 7, 8, 19
Caprini Jet Plane 21
Carbon 18
Catapult 18
Chamber Pressure 10
Chinese, First Use of Rockets 1
Chugs Sounds 38
Clark, Dr. C. 77, 79
Cley Mold for Rocket Shells 96
Color of Gas Flame 35
Combustion Chamber 27
Combustion Chamber Aluminum 44
Congreve, Sir William, 19th Century 1
Constant Pressure Chamber 6
Copenhagen, Attacked by Rockets, 1807 1
Cornishman Trengouse, Life Saving
Coolant for Rocket Motors 64
Rocket, 1807 1
Rocket Tank 85

— D —

Danish 25
Dewark Flask 85
Duraluminum 46

— E —

Earth Gravitation Influence 12
Efficiency, Rocket Fuel 12
Electroscopes 74
Entropy in Nozzles 42
Ethyl Alcohol 20, 21
Exhaust Gas Velocity 68, 69
Explosion Rocket 6
Explosion Speed 11, 12

— F —

Field Rocket Brigade 1, 12, 18
Fins for Cooling 33
Fins for Guiding 33, 36
Four-nozzle Motor 38
Frazier, Suggests Tandem Rocket 2
Frensch 2, 24
Fuels 30, 54, 55
Fuel Pressure 30

— G —

Gasoline 35
Gasoline Tanks or Containers 36
German 2, 9, 14, 19, 23, 81, 88
German Rocket Society 19
Goephysical 74
Goddard, Dr. Robert H., 20th Century, 2, 4, 5, 8, 12, 19, 21, 24, 38, 68, 88
Gravity Center 16
Graphite 46
Graphty 82
Greek, Flaming Projectiles 1
Gunpowder 10
Gyro 77, 82
Gyroscope 74, 84
Gyroscopic Effect 15

— H —

Hale, Introduces Fins for Rockets 1
Haylandt, Dr. Paul, Liquid Fuels 2, 19
High Altitude Rocket 73
Hohmann, Dr. Walter Report 1925 2
Hughes, Howard, Lockheed Plane 16
Hunting Motion 38
Hydrocarbons 14
Hydrogen 13, Liquid 14
Hydrometer 74

INDEX

— I —

Page

Ideal Rocket 12
Interplanetary Space 4
Inventor of Rocket 1

— J —

Jet-Propelled Aircraft 101, 102
Jet-Propelled Wing 34
Jet — Liquid 41
Jet Reaction 41, 56
Jet Rocket 41
Junkers 19

— K —

Kimbal, Dr. James H. 77
Kinetic Energy Jet 50, 62

— L —

Laval Nozzle 62
Launching Rack 36, 79
Lead 46
Leipsic, Attacked by Rockets, 1812 1
Liquid Fuel Rocket 2, 4, 9, 12, 26, 33
Liquid Oxygen 85
Lithium 46
Luft Hansa 18
Lucite Fuel Tank 98
Lucke 41, 42

— M —

Marcus Greacus, 13th Century 1
Mayo's Composite Aircraft 18
Meyer's Equasion 43
Meteorograph 71, 72, 73
Meteorological Rocket 19
Molibdenum 45
Moon 2
Motor, Ideal 41
Motor — Multi-Nozzle 40
Muzzle Velocity 14

— N —

Napoleon, Attacked by Rockets at
Waterloo 1, 23
Nazis 24
Nebel Werfer, German Rockets 16
Netherlands 25
Nitrogen 35
Nitrogen Gas 37
Nitrogen Pressure 39
Nitrogen Tank 38
Nozzle 20, 36
Nozzle Efficiency 62
Nozzle Elongated 30
Nozzle Flare 27, 28, 30
Nozzles, Brass 40
Nozzle Burn Out 39
Nozzle for Diabatic Expansion 42
Nozzle, Multiple 38
Nozzle Reaction 42
Nozzle Steam Turbine 42
Nozzles, Turbine 41

— O —

Oberth, Prof. Herman Robert, 1923
Report 2, 7, 9, 13
Opel, Fritz 2
Oxygen, Heating Regenerative
Principle 7, 10, 13, 43
Oxygen Pouring 35
Oxygen Tank 36, 37
Oxygen Valve 35

— P —

Pelpetrie, Robert Esnault, Report
1926 2, 68
Pick-a-back Plane 18
Parachute 33, 38, 40, 71, 72, 73, 74,
78, 79, 80, 82, 88, 90
Parachute Silk 90
Parachute Ejecting Device 80
Platinum 45
Plastic Rocket 93, 94
Plastics for Tanks and Motors 48
Powder Rockets 90
Projectile 14, 15, 16
Propeller Speed 20
Pulling Cord 33

— Q —

Quartz Motor for Rockets 46

— R —

Radio Activity 10
Radio Meteorograph for Rockets 73, 78
Radio Tone Emeter for Rockets 73
Radio Transmitter 78
Range Finder 77
Recoil Principle 1, 10
Regenerative Motor by Valier 2
Roswell, New Mexico 2
Receiving Radio for Rockets 93
Resistance Air 52
Refractory 55, 76
Rocket Auxiliary 67
Rochetta 1
Robot Bomb 16
Rocket Bomb 16
Rocket Meteorological 68
Rocket Motor 21
Rocket Plane 20
Rocket Projectile 26
Rocket Retardation 57
Rocket Shell 23, 24
Royal Aeronautical Establishment 18
Ruggery Brothers 1
Russian Rockets 16, 88

— S —

Sanger, Dr. 19, 68, 74
Secret Weapon 16
Smith, Sir Sidney, 1805 1
Smithsonian Institute Publishes Dr.
R. H. Goddard's Report, 1919 2
Sky Rocket 36
Smokeless Powder 8, 12
Sounding Balloon 19

INDEX

Page
Sonic-hunting Control 23
Sounding Balloon 71
Sounding Rocket Steering Mechanism 74, 78, 98
Stellite 43
Steering Rocket 93
Stratosphere 71, 84
Substratosphere 72
Swiss 24

— T —

Take-off Performance 16, 17, 20
Tanden Tanks 38
Tanks, Cylindrical 86
Tanks for Fuel Spherical 66, 85, 86
Tank, Oxygen 33
Tanks for Rockets 85
Tantalum 45
Tetraetyl Lead 34
Theodolite 71, 72
Thermojet 101
Thrust, Propeller 20
Thrust Radio for Powder Rockets 20
Tilling, Raymond 74, 80
Timer 34
Titanium 44
Torpedo Rocket 16
Trajectory Rocket 38, 57, 58, 73, 74
Tungsten 45

— U —

UFA Film, Girl in the Moon 2

— V —

Vacuum 27, 31
Valier, Max — Report, 1924 2, 19
Valves 33, 38
Valvemen's Dugout 34
Valve Reducing 66
Valve Safety 36, 79
Velocity Ratio 48
Velocity, Rocket 12
Velocity Rocket 38, 57
Ventury, Cone Principle 20

— W —

Water Cooling 33
Water Jacket 33, 38
Weather Rocket 76
Wick Ignition 35
Winkler 88
Woolwich Laboratory 1
Worcester, Mass. — Dr. Goddard's experimental Report, July 17, 1929 4, 13
Wright Brothers 18

— Z —

Zeppelins 23
Zeuner's Equasion 42
Z-Gun, British 16

Some American Rocket Patents

No. 24,468. "Improvement in Exhibition-Rocket"; granted to Andrew Lanergan, of Boston, Mass.

No. 35,977. "Improvement in War-Rockets"; granted to Thomas W. Roys and Gustavus A. Lilliendahl, of New York, N. Y.

No. 37,940. "Improvement in War-Rockets"; granted to Pascal Plant, of Washington, D. C.

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No. 51,176. "Improvement in Sky-Rockets"; granted to John W. Hadfield, of Newtown, N. Y.

No. 53,933. "Improvement in Rockets"; granted to William Hale, of London, Eng.

No. 58,646. "Improvement in Rockets"; granted to E. S. Hunt, of Weymouth, Mass.

No. 59,487. "Improvement in War-rockets"; granted to J. J. B. Walbach, of Baltimore, Maryland.

No. 79,963. "Improvement in Rocket-Signal Device"; granted to Jacob J. Detwiller, of Greenville, N. J.

No. 87,371. "Improvement in War and Signal-Rockets"; granted to Taliaferro P. Shaffner, of Louisville, Kentucky.

No. 119,630. "Improvement in Rockets"; granted to Cornelius E. Masten, of Boston, Mass.

No. 148,553. "Improvement in Sky-Rockets"; granted to Jacob J. Detwiller, of Jersey City, N. J.

No. 218,394. "Improvement in Rockets"; granted to Charles Morris, of Chicago, Ill.

No. 266,437. "Rocket"; granted to Patrick Cunningham, of New Bedford, Mass.

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No. 479,738. "Dynamite Rocket"; granted to Patrick Cunningham, of New Bedford, Mass.

No. 499,790. "Rocket-Stand"; granted to William H. Meadowcroft, of New York, N. Y.

No. 502,168. "Aerial Machine"; granted to Sumter B. Battey, of New York, N. Y.

No. 508,753. "Airship"; granted to Edwin Pynchon, of Chicago, Illinois.

No. 534,651. "Rocket-Holder"; granted to Henry Krucker, of Cincinnati, Ohio.

No. 585,805. "Rocket"; granted to Otto Wilhelmi, of Dusseldorf, Germany.

No. 757,825. "Rocket Apparatus for Taking Photographs"; granted to Alfred Maul, of Dresden, Germany.

No. 791,408. "Rocket"; granted to Harrison P. Diehl, of Lawrenceburg, Ind.

No. 847,198. "Rocket Apparatus"; granted to Alfred Maul, of Dresden, Germany.

No. 918,336. "Aerial Navigation"; granted to Christopher John Lake, of Bridgeport, Conn.

No. 947,904. "Floating and Luminous Line-Carrying Rocket"; granted to Henri E. A. Guerard, of Graville Ste. Honorine, France.

No. 957,210. "Rocket"; granted to Thomas G. Hitt, of Seattle, Wash.

No. 976,732. "Gyroscopic Rocket"; granted to Nicolas Gherassimoff, of St. Petersburg, Russia.

No. 1,102,653. "Rocket Apparatus"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,003,411. "Pyrotechnical Auxiliary Mechanism for Aerostructures"; granted to Haden H. Bales, of Ashcroft, British Columbia, Canada.

No. 1,103,503. "Rocket Apparatus"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,191,299. "Rocket Apparatus"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,194,496. "Rocket Apparatus"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,206,837. "Rocket Apparatus"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,297,898. "Rocket"; granted to Henry J. Pain, of New York, N. Y.

No. 1,299,217. "Rocket"; granted to Henry J. Pain, of New York, N. Y.

No. 1,311,855. "Magazine Rocket"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,326,493. "Signal-Rocket"; granted to Robert C. Gowdy, of Cincinnati, Ohio.

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No. 1,341,053. "Magazine Rocket"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,362,997. "Propelling Apparatus"; granted to Boris Koleroff, of New York, N. Y.

No. 1,376,797. "Rocket"; granted to Wm. W. Case, of Frenchtown, N. J.

No. 1,440,175. "Rocket"; granted to Dmitri Riabouchinski, of Guethary, France.

No. 1,645,427. "Rotary-Balanced Rocket"; granted to Thomas G. Hitt, of Seattle, Washington.

No. 1,653,178. "Rocket"; granted to Thomas G. Hitt, of Seattle, Wash.

No. 1,666,534. "Revolving Rocket"; granted to Thomas G. Hitt, of Seattle, Wash.

No. 1,666,598. "Rocket"; granted to Thos. G. Hitt, of Seattle, Wash.

No. 1,803,366. "Signal Rocket"; granted to Charles C. Stetson, of St. Paul, Minn.

No. 1,809,271. "Propulsion of Aircraft"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,823,378. "Rocket"; granted to Chas. Scardone, of Elkton, Md.

No. 1,834,149. "Means for Decelerating Aircraft"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,838,984. "Rocket Motor Aeroplane"; granted to Louis Berkowitz, of New York, N. Y.

No. 1,856,552. "Carbide Rocket"; granted to Frank Hadamik and Nick Liberatore, of Union, N. Y.

No. 1,879,187. "Mechanism for Directing Flight"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,879,579. "Rocket"; granted to Hermann Stolfa and Rudolf Zwerina, of Vienna, Austria.

No. 1,880,579. "Method of Producing Rockets, especially for Aeronautic Purposes"; granted to Reinhold Tiling, of Osnabruck, Germany.

No. 1,880,586. "Flying Rocket"; granted

No. 1,901,852. "Rocket"; granted to Hermann Stolfa and Rudolf Zwerina, of Vienna, Austria.

No. 1,903,303. "Flying Rocket"; granted to Reinhold Tiling, of Osnabruck, Germany.

No. 1,979,757. "Liquid Fuel Burner"; granted to Henri F. Melot, of Montrouge, France.

No. 1,980,266. "Propulsion Apparatus"; granted to Robert H. Goddard, of Worcester, Mass.

No. 1,982,665. "Explosion Turbine"; granted to Hans Holzwarth, of Dusseldorf, Germany.

No. 1,982,666. "Apparatus for Charging Explosion Chambers"; granted to Hans Holzwarth, of Dusseldorf, Germany.

No. 1,983,405. "Method of Producing Motive Forces on Aircraft, by the Explosion of Inflammable Mixtures of Substances"; granted to Paul Schmidt, of Munich, Germany.

No. 1,994,490. "Rocket Projectile"; granted to Leslie A. Skinner, of the United States Army, Aberdeen Proving Ground, Md.

No. 2,206,809. "Projectile"; granted to Paul E. L. Denoix, of Paris, France.

No. 2,016,921. "Means for Cooling Combustion Chambers"; granted to Robert H. Goddard, of Worcester, Mass.

No. 2,024,274. "Reaction-propulsion Method and Plant"; granted to Secondo Campini, of Milan, Italy.

No. 2,026,885. "Aircraft"; granted to Robert H. Goddard, of Roswell, New

No. 2,041,081. "Rocket Engine"; granted to Walter R. Menzies, of Milwaukee, Wisconsin.

No. 2,043,268. "Rocket"; granted to Leslie A. Skinner, of the United States Army, Aberdeen Proving Ground, Md.

No. 2,085,761. "Aircraft Power Plant"; granted to Alf Lysholm, of Stockholm, Sweden.

No. 2,085,800. "Combustion Apparatus"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,086,618. "Rocket"; granted to Thos. G. Hitt, of Seattle, Wash.

No. 2,090,039. "Igniter"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,122,521. "Cooling Jacket Construction"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,124,462. "Rocket Engine"; granted to Charles R. Cummings, of Fernwood, Pa.

No. 2,158,180. "Gyroscopic Steering Apparatus"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,183,311. "Means for Steering Aircraft"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,183,312. "Fuel Storage and Discharge Apparatus"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,183,313. "Combustion Chamber for Aircraft"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,183,314. "Gyroscopic Apparatus for Directing Flight"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,191,841. "Rocket"; granted to Rudolf Zwerina, of Vienna, Austria.

No. 2,206,057. "Bocket Projectile"; granted to Leslie A. Skinner, of the United States Army, Berkeley, Calif.

No. 2,217,649. "Combustion Chamber for Rocket Apparatus"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,256,198. "Aircraft Power Plant"; granted to Max Hahn, of Seestadt Rostock, Germany.

No. 2,271,224. "Parachute Attachment for Aircraft"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,283,863. "Rocket Engine"; granted to Ernest Acterman, of Westfield, N. J.

No. 2,286,908. "Auxiliary Turbine for

No. 2,286,909. "Combustion Chamber"; granted to Robert H. Goddard, of Roswell, New Mexico.

No. 2,307,125. "Rocket Launching Device"; granted to Robert H. Goddard, of

"Improvement in Exhibition-Rocket", No. 24,468; granted to Andrew Lanergan, of Boston, Mass.

"Improvement in War-Rockets", No. 35,977; granted to Thomas W. Roys and Gustavus A. Lilliendahl, of New York, N. Y.

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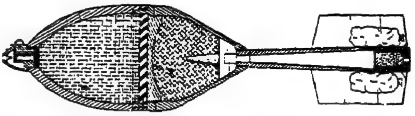
"Propelling Device," No. 1,375,601; granted to Ernest Morize, of Chateaudun, France.

"Rocket", No. 1,376,797; granted to William W. Case, of Frenchtown, N. J.

"Rocket", No. 1,440,175; granted to Dmitri Riabouchinski, of Guethary, France.

"Propelling Ejector," No. 1,493,157; granted to H. F. Melot, of Paris, France.



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"Pistol Rocket," No. 2,344,957; granted to Ralph Anzalone, of Oceanside, N. Y.

BRITISH PATENT SPECIFICATIONS

No. 392, Boulton, M. P. W., Feb. 5, 1868.

No. 1,763, Macleod, M. C., Jan. 23, 1904.

No. 2,115, Butler, J. W., and Edwards, E., July 19, 1867.

No. 2,680, Hunter, J. M., Aug. 29, 1868.

No. 2,923, David E., Feb. 5, 1902.

No. 3,561, Kerkhove, A. H. van de, and Snyers, T., Aug. 16, 1881.

No. 4,245, Johnson, J. H., Sept. 3, 1883.

No. 7,919, Hofmann, J., April 21, 1894.

No. 8,182, Johnson, J. Y., June 7, 1887.

No. 10,068, Griffiths, T., Aug. 25, 1885.

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No. 11,905, Skouses, P., June 13, 1907.

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T. H. W., Aug. 7, 1890.

No. 15,977, Battey, S. B., Sept. 6, 1892.

No. 16,886, Hayot, L. A., Aug. 1, 1912.

No. 17,842, Marconnet, G. A., July 29, 1897.

No. 118,123, Harris, H. S., Aug. 16, 1917.

No. 124,736, Morize, O., July ,26, 1917.

No. 145,441, Silva, R. R. da, and Maderios e Albuquerque, J. de, Nov. 5, 1918.

No. 157,781, Guaita, A., Nov. 27, 1920.

No. 256,684, Helfenstein, A., May 12, 1925.

No. 291,263, Hallowell, E., Aug. 19, 1927.

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THE ROCKET SOCIETIES

Amateur Research Society, Clifton, N. J. Founded 1937. First President, Nicholas Swerduk.

American Institute for Rocket Research, Chicago, Ill. Founded 1936, by C. W. McNash. First President, C. W. McNash.

American Rocket Society (formerly American Interplanetary Society), 120 West 42nd St., New York City. Founded 1930, by Warren Fitzgerald, David Lasser, William Lemkin, Everett Long, Laurence E. Manning, C. P. Mason, G. Edward Pendray, Fletcher Pratt, Nathan Schachner, and C. W. Van Devander. First President, David Lasser; Present President, James H. Wyld.

Bulletin, Nos. 1-18 (June 1930 - April 1932) **Astronautics,** Nos. 19 - 60 (May 1932 - Dec. 1944).

Astronautical Development Society, Surrey, England. Founded 1938, by K. W. Gatland and H. N. Pantlin.

Spacecraft, Dec. 1941.

Spacewards, Vol. 4-5 (Oct. 1942 - April 1944). 7 issues.

Bulletin, Vol. 4-5 (Mar. 1942 - Feb. 1944). 24 issues.

Australian Rocket Society, Brisbane, Australia. Founded 1936, by Alan H. Young and Noel S. Morrison. First President, Alan H. Young.

Australian Rocket Society, 219 High St., Prahran, Melbourne, Australia. Founded 1941, by J. A. Georges. First President, J. A. Georges; Present President, same.

British Interplanetary Society, London, England. Founded 1933, by P. E. Cleator. First President, P. E. Cleator.

Journal, Vols. 1-5 (Jan. 1934 - July 1939). 12 issues.

Bulletin, Vols. 1-3 (Oct. 1934 - Aug. 1939). 29 issues.

California Rocket Society, 1764 Garth Ave., Los Angeles 35, Calif. Founded 1940, by Bernard Smith. First President, Bernard Smith; Present President, same.

Cleveland Rocket Society, Cleveland, Ohio. Founded 1933, by Edward L. Hanna and Ernst Loebell. First Chief Engineer, Ernst Loebell.

Space, Vol. 1 (July 1934-). 4 issues.

Combined British Astronautical Societies, Northern Headquarters, 2 Hillview Road, Denton, Manchester, England. Founded 1944, by the A.D.S. and the M.A.A. First President, E. Burgess; Present President, E. Burgess.

Spacewards, Vol. 5-6 (July-Oct. 1944). 2 issues.

Bulletin, Vol. 6 (Mar.-Aug. 1944). 6 issues.

Fortschrittliche Verkehrstechnik e.V. (Interplanetary Society of Germany), Berlin. Reorganized 1933, by Willy Ley and Dr. Otto Steinitz. First President, Major Hanns Wolf von Dickhuth-Harrach.

Das Neue Fahrzeug, Vol. 1- (Feb. 1933-1937). 20 issues.

GALCIT Rocket Research Project, California Institute of Technology, Pasadena, Calif. Founded 1936, by Weld Arnold, Edward S. Forman, Frank J. Malina, John W. Parsons, A. M. O. Smith, and Hsue-Shen Tsien. First Chairman, Dr. Th. von Karman.

Research Papers, R1 - R-7.

Gesellschaft fur Weltraumforschung e.V. (Society for Space Investigation), Breslau, Germany. Founded 1938, by Hans K. Kaiser. First Sec., Hans K Kaiser.

Astronomische Rundschau (Astronomical Survey), Nos. 1-4 (Jan. 1938-Dec. 1938).

Weltram (Space), Nos. 1-4 (Jan. 1939 Dec. 1939).

Glendale Rocket Society (formerly Southern California Rocket Society), 3262 Castera Ave., Glendale 8, Calif. Founded 1943, by George James. First President, George James; Present President, John Cipperly.

Bulletin, Nos. 1-7 (Aug. 1943 - Feb. Mar., 1944).

Indian Air Mail Society, Calcutta, India. Present Sec., Stephen H. Smith.

Quarterly Bulletin.

Len-GIRD (Group for the Study of Reactive Motion), Leningrad, Russia. Founded 1929, by Prof. Nikolai Rynin and Dr. Jakow I. Perlmann.

Manchester Astronautical Association, 2 Hillview Road, Denton, Manchester, England. Founded 1937, by E. Burgess and T. Cusack. First President, E. Burgess.

Spacewards, Vol. 1-5 (Aug. 1939 - April 1944). 19 issues.

Bulletin, Vol. 1-5 (1938 - Feb. 1944).

Manchester Interplanetary Society, Manchester, England. Founded 1936, by E. Burgess. First President, E. Burgess.

Astronaut, Vol. 1-2 (Apr. 1937 - Aug. 1938). 6 issues.

M.I.T. Rocket Club, Massachusetts Institute of Technology, Cambridge, Mass. Founded 1941.

M.I.T. Rocket Research Society, Massachusetts Institute of Technology, Cambridge 39, Mass. Founded 1940, by George Burdick and Robert Youngquist. First President, Robert Youngquist; Present President, John C. Cook.

Papers on Rocketry, Publications 1-4.

Mos-GIRD (Group for the Study of Reactive Motion), Moscow, Russia. Founded 1929, by Ing. Ivan Petrovich Fortikov.

Nederlandse Rakettenbouw (Dutch Rocket Society), s'Gravenhage, Holland. Founded 1934, by Mijnheer Gerard A. G. Thoolen.

Oesterreichische Gesellschaft fur Raketentechnik (Austrian Society for Rocket Technology), Vienna, Austria. Founded 1931, by Rudolf Zwerina and Count Guido von Pirquet. First President, Ing. Rudolf Zwerina.

Paisley Rocketeers Society, Paisley, England. Founded 1936, by John D. Stewart. First President, John D. Stewart.

Peoria Rocket Association, Peoria, Ill. Founded 1934, by Ted S. Cunningham. First President, T. S. Cunningham.

Journal, Nos. 1-4 (Jan.-Apr. 1939).

Rocket Society of the American Academy of Sciences, Savannah, Ga. Founded 1918, by Dr. Matho Mietk-Liuba. First President, Dr. Matho Mietk-Liuba.

The Rocket, No. 1 (Feb. 19, 1944).

United States Rocket Society, Box 29, Glen Ellyn, Ill. Founded 1942, by R. L. Farnsworth. First President, R. L. Farnsworth; Present President, same.

Rocket Flight, No. 6 (Mar. 1943).

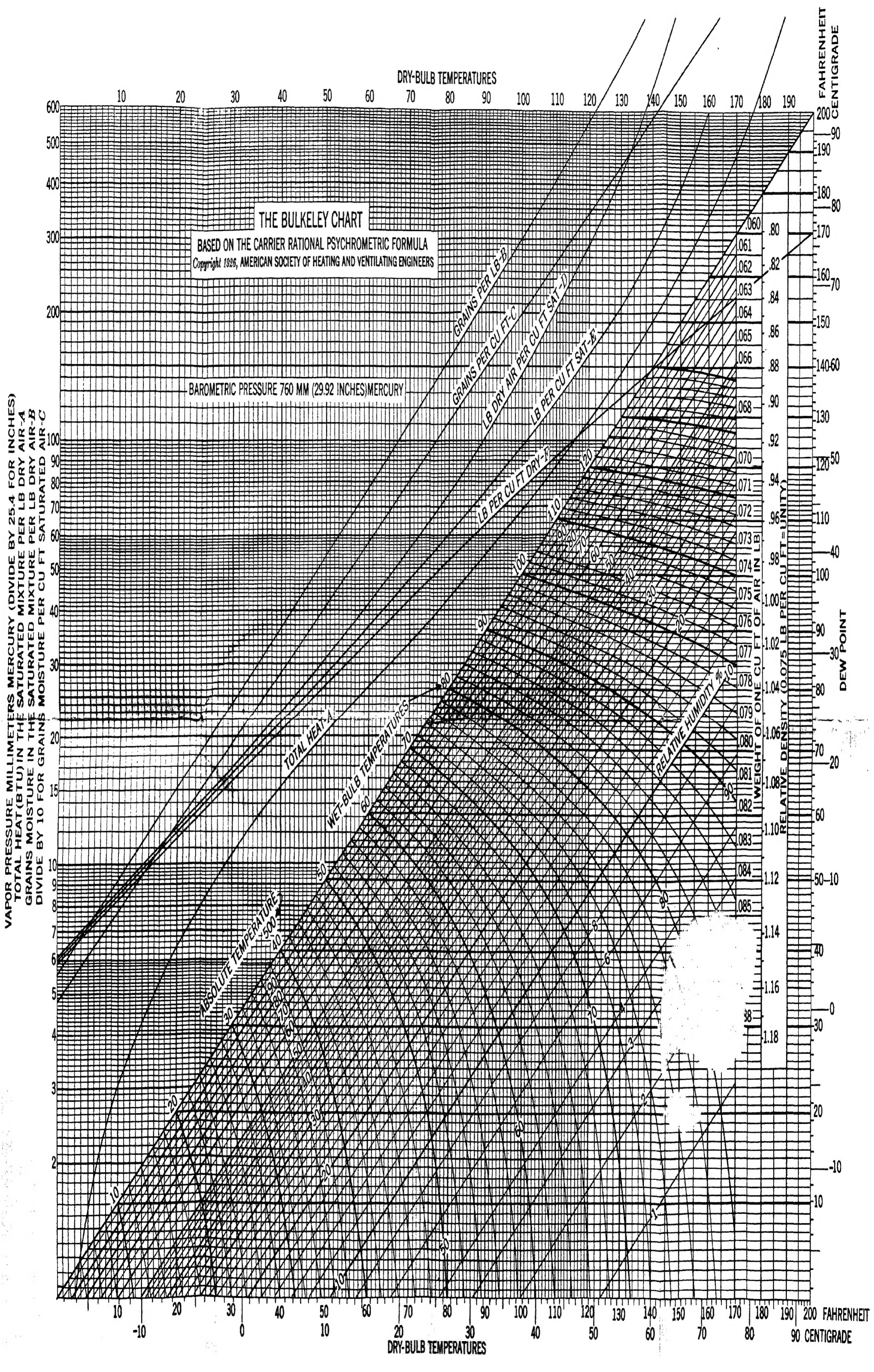
Verein fur Raumschiffahrt, e.V. (Society for Space Navigation), Breslau, Germany. Founded 1927, by Max Valier and Johannes Winkler. First President, Johannes Winkler.

Die Rakete, Vol. 1-3 (Jan./June, July 1927 - Nov./Dec. 1929). 30 issues.

Westchester Rocket Society, Westchester, N. Y. Founded 1936.

Wissenschaftliche Gesellschaft fur Hohenforschung (Scientific Society for Altitude Explorations), Austria. Founded 1926, by Dr. Franz von Hoefft.

Yale Rocket Club, New Haven, Conn. Founded 1935, by Franklin M. Gates. First Chairman, Franklin M. Gates.



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